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NAVSHIPS 250-649-1

SUBMARINE ATMOSPHERE HABITABILITY DATA BOOK

APRIL 1961 OLD

BUREAU OF SHIPS · NAVY DEPARTMENT · WASHINGTON 25, D.C.

DEPARTMENT OF THE NAVY
BUREAU OF SHIPS
WASHINGTON 25, D. C.

IN REPLY REFER TO

27 April 1961

From: Chief, Bureau of Ships
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Subj: NAVSHIPS 250-649-1, Submarine Atmospheric Habitability Data Book (preliminary draft); forwarding of

1. The subject publication was prepared at the request of Forces Afloat to coordinate and disseminate information on submarine atmospheric habitability and to establish a procedure for collecting and disseminating future information as it becomes available. Because atmosphere control in nuclear powered submarines is a relatively new and changing field, a close working relationship between the Bureau and submarine operating personnel is vital to meeting operational requirements. Therefore, this publication is conceived as a flexible medium of communication which can be modified and amended easily and rapidly. Its contents will ultimately be incorporated in the Bureau of Ships Manual after the field has stabilized.

2. This preliminary draft is forwarded for comment as to format and technical content. Such comment is requested from Forces Afloat by 1 September 1961 and comment by others is also invited.

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Section 1 - INTRODUCTION

101 PURPOSE AND SCOPE

1. This publication has two basic purposes, (1) to disseminate presently available scattered information on submarine atmospheric habitability in a unified fashion to personnel concerned with operations of nuclear powered submarines and (2) to establish a procedure for collecting and disseminating information which becomes available in the future. For the purposes of this publication, atmospheric habitability is defined as control of the chemical aspects of the atmosphere to meet the requirements of equipment and personnel. It is concerned with ventilation and air conditioning only where they affect chemical control.

2. In regard to dissemination of current information, this publication is not intended to duplicate instruction books but rather to supplement and coordinate them and, by means of references, permit the reader to obtain detailed information on chemical principles, experimental results, operating experience, etc.

3. A loose-leaf format has been adopted to facilitate making changes and additions, and addressees receiving the basic book will receive subsequent material. Bureau of Ships, Code 649, will serve as a clearing house for information and all suggestions and recommendations in the field of submarine atmosphere control should be directed to the attention of this Code.

102 General Principles of Submarine Atmosphere Control

1. Table 1-1 outlines the overall problem of submarine atmosphere control. With the exception of "Temperature and Humidity", underlying principles of each factor will be discussed below.

2. O_2 Supply and CO_2 Removal

Human respiration accounts for essentially all of the O_2 consumption and CO_2 production in a submarine. Although numerous other processes such as smoking, cooking, aerobic bacterial action, etc. also affect these gases, they do so to a negligible degree. For engineering purposes, a man can be considered to be an engine which burns food for fuel as follows:

$$\text{food} + O_2 \longrightarrow CO_2 + H_2O + \text{energy}$$

The ratio of the volume of CO_2 produced to the volume of O_2 consumed is called the respiratory quotient, i.e., $\frac{CO_2}{O_2} = \text{R.Q.}$

Although R.Q. is affected by diet and shows short term fluctuations due to exercise, eating, etc., for extended periods of time, the normal value is about 0.85. This value has been supported by shipboard studies in which the entire ship's R.Q. has been determined.(*1 & 2)

O_2 consumption rates for a man are quite variable over short periods of time and they are highly dependent on the level of activity as shown in Table 1 - 2 (*3.) However, for

(*1 & 2) Refers to References at end of text.

typical submarine conditions, 1.0 scf O_2/man is a normal rate for extended operations. The corresponding CO_2 rate then is 0.85 scf/man hour (0.1 lb/man hr). Short term fluctuations have relatively little effect on atmospheric concentrations because of the large volume of air per man in submarines (i.e., the "flywheel" effect).

Figure 1-1 shows the changes in O_2 and CO_2 concentrations to be expected in a typical nuclear powered submarine in the absence of control facilities. This plot is based on a volume/man of 700 ft^3 and the above mentioned normal rates so it is only approximately true for a particular ship and occasion. However, it does illustrate the fact that CO_2 becomes a problem before O_2 and it can be used to predict time available before control of these gases is required.

3. Gaseous Contaminants

These materials are of concern because of actual or possible effects on equipment and personnel. The number of possibilities is virtually limitless from many sources (e.g., personnel, machinery, cooking, sanitary facilities, atmosphere control facilities) and a continuing effort is required to determine what materials are actually present in significant quantities. Table 1-3 lists materials identified to date (*4, 5, 6) with concentrations which are acceptable for 90 day exposures. It should be realized that these concentrations are average values for continuous exposure and that they can be temporarily

exceeded as long as there are corresponding periods of low concentrations. However, there are also short term acute concentrations which must not be exceeded even though the average remains acceptable. For guidance, one hour limits are being determined and will be disseminated when available.

In considering the suitability of materials for use in submarines, it is essential to understand the distinction between toxicity and hazard. A material may be toxic but not hazardous because there is no threat of its inhalation by personnel. BUSHIPS Instruction 91940.40 of 24 April 1959 pointed out the clear need to restrict or eliminate several categories of material in nuclear submarines in order to reduce atmospheric contamination. Specific attention was directed to elimination of the use (while submerged) of all organic solvents and oil-based paints. It was pointed out that everything brought aboard which may be volatile should be questioned as a source of atmospheric contaminants. Whenever doubt existed respecting any material which could not be resolved locally, inquiries were to be directed to the Bureau of Ships. In reply to inquiries received subsequently, the following is offered in amplification of the above.

a. Organic solvents include:

(1) Hydrocarbon solvents: Mineral spirits (varsol, dry-cleaning solvent, Stoddard solvent) NOTE: Items in parentheses are identical or closely similar to preceding compound.

(2) Chlorinated solvents: Carbon tetrachloride, methyl chloroform (1,1,1 - trichloroethane, Inhibisol), trichloroethylene, and perchloroethylene.

(3) Alcohols: Methanol (mimeographing fluid), ethanol

(4) Any compound containing high concentrations of (1), (2), or (3) such as methanol-based shellac.

b. Paints - BUSHIPS Instruction 9190.40 stated that, while submerged, only a specified water-based paint should be used. Other candidate water-based paints are under evaluation. The use of oil-based paints was restricted to a period at least 30 days prior to extended submergence.

c. Mercury - Mercury-containing instruments have been eliminated from nuclear propulsion plants and the use of such instruments has been eliminated during manufacture and test of such plants. (*10) Further, there has been an active program to eliminate mercury-containing instruments from any application aboard nuclear submarines. Mercury-containing thermometers and psychrometers are two examples of this. (*11) Since conventional mercury dry cell batteries are vented, their use has not been approved. However, the use of encapsulated mercury dry cells has been approved on a case basis in several applications pending the availability of suitable non-mercury type cells. (*12)

d. Pipe Hanger Fluids- "Dowtherm A" and "Dow-Corning 550 Fluid" have been found to present no appreciable hazard (even though the former may have an objectionable odor).

e. Deck (resilient tile) wax - Current instructions call for use only at dockside while exhausting to weather. (*13)

f. Shoe polishes and "push-button" pressurized shave creams. The composition of commercial items varies somewhat. However, preliminary study indicates that normal use in a submarine might result in the daily liberation (per ship) of from one to three ounces of such solvents as kerosene or turpentine and/or a similar amount of propellant such as butane or Freon-12. At this time, the amounts involved are not considered significant relative to the amounts of similar compounds originating from other sources. Study of these items is continuing.

g. Other hydrocarbon-containing specialties. As with the shoe polishes and shaving creams mentioned above, there are many specialties containing hydrocarbon solvents which in normal use will present no significant problem. Normal use of lighter fluid in cigarette lighters is one example of this. (If however, several cans of such fluid are used as for general cleaning there would be significant contamination of the air.) Further, intermittent use of light penetrating oils in quantities of up to several ounces is not considered objectionable.

h. Verifax activator - The composition of this item was determined by Naval Research Laboratory. (*14) Storage of the chemicals or the water solution used should present no problem whatever from the standpoint of evolved gases or products.

i. In progress- Requests for information have been received concerning Selsun (selenium sulfide) shampoo, dye penetrants, and coatings applied to Polaroid pictures. Findings will be transmitted in later issues of this publication, as will data obtained on other items studied in the interim.

j. Local actions - It is hoped that this publication will serve as a clearing house for information of this type. In this connection, addressees are urged to inform the Bureau (Code 649) of all items considered locally and the action taken. Again, when doubt exists locally an inquiry should be addressed to the same Code. The inquiry should include all label and brochure information available locally.

It should be realized that the effects of contaminants on personnel may be either immediately apparent or subtle. The following is quoted from industrial hygiene literature (*15) to emphasize that lack of short term effects should not lead to carelessness in avoiding atmospheric contamination.

"Most occupational disease other than dermatitis not only develops slowly but is also extremely non-specific. Frequently it cannot be accurately differentiated from the normal aging process. In fact, it can best be described in physiological terms as an acceleration of the aging process. The worker grows old before his time, his most efficient production capacity is soon lost, and during his productive lifetime he does not enjoy maximal health or contribute in maximal amount to his family, his community or his employer. Even when diagnosis

of occupational disease is possible, it all too often comes too late to conserve health because the physiological changes which make diagnosis possible are usually irreversible."

4. Particulate Contaminants

Comments under "Gaseous Contaminants" apply equally to particulates. However, a clear distinction should be made between particulates ("aerosols") and gases and vapors. The former may be either solids or liquids but they are discrete particles larger than molecules but small enough to remain airborne under submarine conditions. Equipment provided for aerosol control (e.g. electrostatic precipitators, & filters) is not effective against gases and vapors. Similarly, equipment provided for gas and vapor control (e.g., carbon, catalytic burners) is generally not effective against aerosols.

Shipboard studies to date indicate that the principal source of aerosols in submarines is tobacco smoking (*4, 5, 6) but machinery is also an important source - at least, in machinery spaces. (*6) Aerosols are produced either mechanically, (e.g., grinding, atomization), thermally (e.g., condensing vapors) or chemically (e.g., solid product formed by reaction of gases or vapors).

5. Detection and Analysis

Detection and analysis facilities are necessary in submarines for (1) control of routine or recurrent atmospheric constituents and (2) investigation of unexpected or infrequent contaminants.

For (1), in nuclear powered submarines, the Atmosphere Analyzer system and the hydrogen detectors are provided and, for (2), the Draeger Gas Detector Kit and similar equipment is provided. The third type of equipment provided is for back-up and this includes the Dwyer CO_2 Analyzer, the Beckman O_2 Analyzer, the NBS Colorimetric CO Detector Tubes, and the portable hydrogen detector.

103. Basic Concepts of Submarine Atmosphere Control Design

1. The One-Volume Concept

Although submarines are divided into compartments to improve watertight integrity, atmosphere control is based on maintaining a homogeneous atmosphere throughout the ship. Thus, atmosphere control facilities are located on the basis of shipbuilding requirements and ease of operation without regard to local atmosphere requirements. For example, CO_2 removal is accomplished at one location although it is produced throughout the ship and O_2 is introduced in one or two locations although it is consumed throughout the ship. An important result of this concept is that, generally speaking, one compartment cannot be isolated without upsetting the overall atmosphere control system. While this is undesirable from the standpoint of controlling casualties, the alternative of multiple equipment or additional ducting is felt to be more undesirable.

2. Regenerative vs. Non-Regenerative Systems

Figure 1-2 illustrates the basic differences between regenerative and non-regenerative systems. The former can be said to consume power and the latter to consume material. The necessity for regenerative systems for long submergence nuclear powered submarines is obvious in terms of volume and weight but for battery submarines the low power requirements may be as important as the small volume and weight. A similar relationship exists between chlorate candles and generators for supplying O_2 but the values are different and they are more subject to change because of current research and development. One other basic difference between regenerative and non-regenerative systems for submarines is complexity. The former are considerably more complicated even though the principle may be quite simple (e.g., electrolysis of water).

3. Another basic concept pertains to requirements and these have been divided into three classes - routine, backup, and emergency. Routine atmosphere control facilities are provided where normal operations of the ship require them as in the case of nuclear powered submarines. Routine facilities are also provided in some cases for battery powered submarines such as the Fast Attack Class and the former troop carriers. Backup facilities may consist of either alternate methods or duplicate equipment. This concept applies only to nuclear powered submarines and current practice is to provide duplicate equipment although

initially, alternate methods are usually used (e.g., lithium hydroxide with MEA scrubbers, chlorate candles with O_2 generators). Emergency facilities are provided in all submarines as an aid to survival under conditions of no power. This can either be to maintain a respirable atmosphere at normal pressure while awaiting rescue or, in older battery powered submarines, to permit escape by "flooding up".

104. Submarine Atmosphere Control Facilities

Table 1-4 tabulates facilities currently provided for nuclear powered submarines and battery powered submarines to meet routine and emergency requirements. Each of the items will be discussed in following chapters.

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TABLE 1-1

ELEMENTS OF SUBMARINE ATMOSPHERE CONTROL

I. Gases

(a) O_2 Supply

(b) CO_2 Removal

(c) Contaminant Removal (odors, toxic materials)

II. Particulates

(a) Solid Contaminant Removal

(b) Liquid Contaminant Removal

III. Detection and Analysis

IV. Temperature and Humidity

TABLE 1-2

O_2 AND AIR CONSUMPTION AS A FUNCTION OF ACTIVITY

ACTIVITY	O_2 CONSUMPTION (SCF/MAN HR)	AIR CONSUMPTION (SCF/MAN HR)
Bed Rest (Basal)	0.57	14
Sitting Quietly	0.68	16
Standing	0.91	18
Walking, 2mph	1.6	34
Walking, 4mph	2.7	59
Running, 8mph	4.6	100
Uphill Running	9.1	190

TABLE 1-3

COMPOUNDS IDENTIFIED OR SUSPECTED IN SUBMARINE ATMOSPHERES

Compound	Chemical Formula	Suspected Source	Limit (max) for 90 Day Dive (NOTE 2)	Remarks
Acetylene	C_2H_2		2.5% 2.5	Limit not physiological, but is lower explosive limit
Acrolein	$CH_2CH\ CHO$	Cooking	(NOTE 3) 0.5	
Arsine	AsH_3	Battery gassing	(NOTE 3) 0.05	
Ammonia	NH_3	Scrubbers	(NOTE 3) 100 ppm (20c ACT) Single	
Carbon Dioxide	CO_2	Breathing	1% (1% 3%)	
Carbon Monoxide	CO	Smoking	50 ppm 100	
Chlorine	Cl_2	Chlorate Candles	0.5 ppm 1	
Ethylene	C_2H_4	Polyethylene Decomposition	(NOTE 3)	
Formaldehyde	CH_2O	Cooking, combustion	(NOTE 3) 5	
Freon -12	CCl_2F_2	Air Conditioning	500 ppm	See also HCl, HF, and $COCl_2$
Hydrocarbons (other than CH_4)	--	Paints	(NOTE 3)	

TABLE 1-3, continued

Compound	Chemical Formula	Suspected Source	Limit(max) For 90 Day Dive (NOTE 2)	Remarks
Hydrogen	H_2	Battery gassing	3% 3%	Limit not physiological, but is based on lower combustible limit
Hydrogen Chloride	HCl	Freon Decomposition	0.1 ppm 5	
Hydrogen Fluoride	HF	Freon Decomposition	0.1 ppm 3	
Mercury	Hg		0.05mg/m^3 0.1	2.0 very complicated suggestion from ACT
Methane	CH_4	Sanitary Tanks	5.3%	Limit not physiological, but is lower explosive limit
Methyl Alcohol	CH_3OH		3 ppm 200	(500 ACT) single
Monoethanolamine	$HOCH_2CH_2NH_2$	CO_2 Scrubbers	1 ppm 2.0 (40 hrs)	(20 8 hrs) single
Nitrogen	N_2		--	
Nitrogen Dioxide	NO_2	Burners, smoking	0.5 ppm 5 ppm	
Nitric Oxide	NO	Burners, smoking	(NOTE 3)	
Oxygen	O_2		17% min. 0.1	
Ozone	O_3	Precipitators	0.05 ppm 0.1	(1.0 ACT) ?
Phosgene	$COCl_2$	Freon Decomposition	0.1 ppm 1	

TABLE 1-3, continued

Compound	Chemical Formula	Suspected Source	Limit(max) For 90 Day Dive (NOTE 2)	Remarks
Stibine	SbH_3	Battery gassing	(NOTE 3)	0.1
Sulfur Dioxide	SO_2	Oxidation sanitary tank gases	(NOTE 3)	5
Triaryl phosphate (NOTE 4)	- -	Compressors	0.06 ppm (1mg/m^3)	10.0 (30 days)

NOTES

NOTE 1 - Modified from NRL Report 5456 and subsequent studies by NRL and US Public Health Service

NOTE 2 - These limits have been established by the Bureau of Medicine and Surgery. They should not be regarded as fine lines between safe and dangerous conditions. They represent conditions under which it is believed personnel may be exposed continuously for 90 days without adverse effects.

NOTE 3 - Limits for these compounds are being established.

NOTE 4 - Hydraulic fluids (also used as compressor lubricants) procured under Specification MIL-H-19457.

NOTE 5 - Additional request is being prepared asking for information to be included in later issues of this publication concerning:

a. Safe limits for isolated one (1) hour exposures
b. Effects of exceeding 90 day or one (1) hour limits.

TABLE 1-4

ATMOSPHERE CONTROL FACILITIES

Operation	Facility: ROUTINE		EMERGENCY	
	SS SS	SSN SSN	SS SS	SSN
O_2	flask*, candles*	flask candles generator	flask	flask
CO_2	LiOH*	MEA	LiOH	LiOH
CO	----	Burner	----	EABS
H_2	Burner*	Burner	----	----
Aerosol	ESP*	ESP	----	EABS
Odor	Small Carbon	Large Carbon	----	EABS
Analysis	Dwyer CO_2 Beckman CO_2* H_2 Detector NBS CO } +Mark III		----	Draeger

NOTE: * = not on all ships

KEY:
- SS = battery powered submarine
- SSN = nuclear powered submarine
- LiOH = pelletized lithium hydroxide
- MEA = Monoethanolamine scrubber (Mare Island design)
- ESP = Electrostatic precipitator
- Mark III = Mark III Atmosphere Analyzer
- EABS = Emergency air breathing system
- Draeger = Draeger Gas Detector Kit
- NBS CO = National Bureau of Standards carbon monoxide detector

EFFECT OF NO O_2 OR CO_2 CONTROL ON TYPICAL NUCLEAR POWERED SUBMARINE

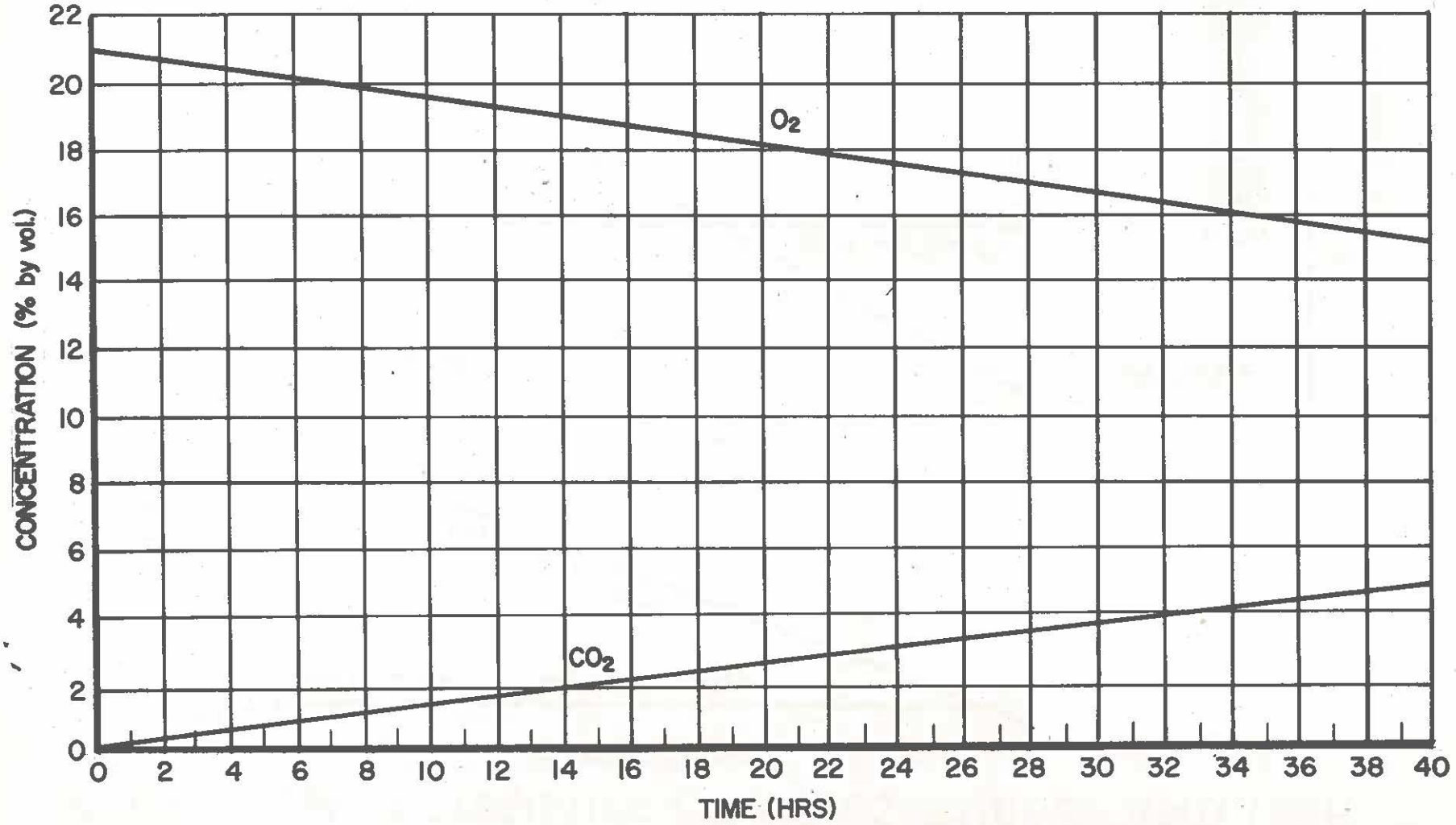


FIGURE 1-1

SYSTEM CHARACTERISTICS OF MEA SCRUBBER AND LiOH

(based on 100 men)

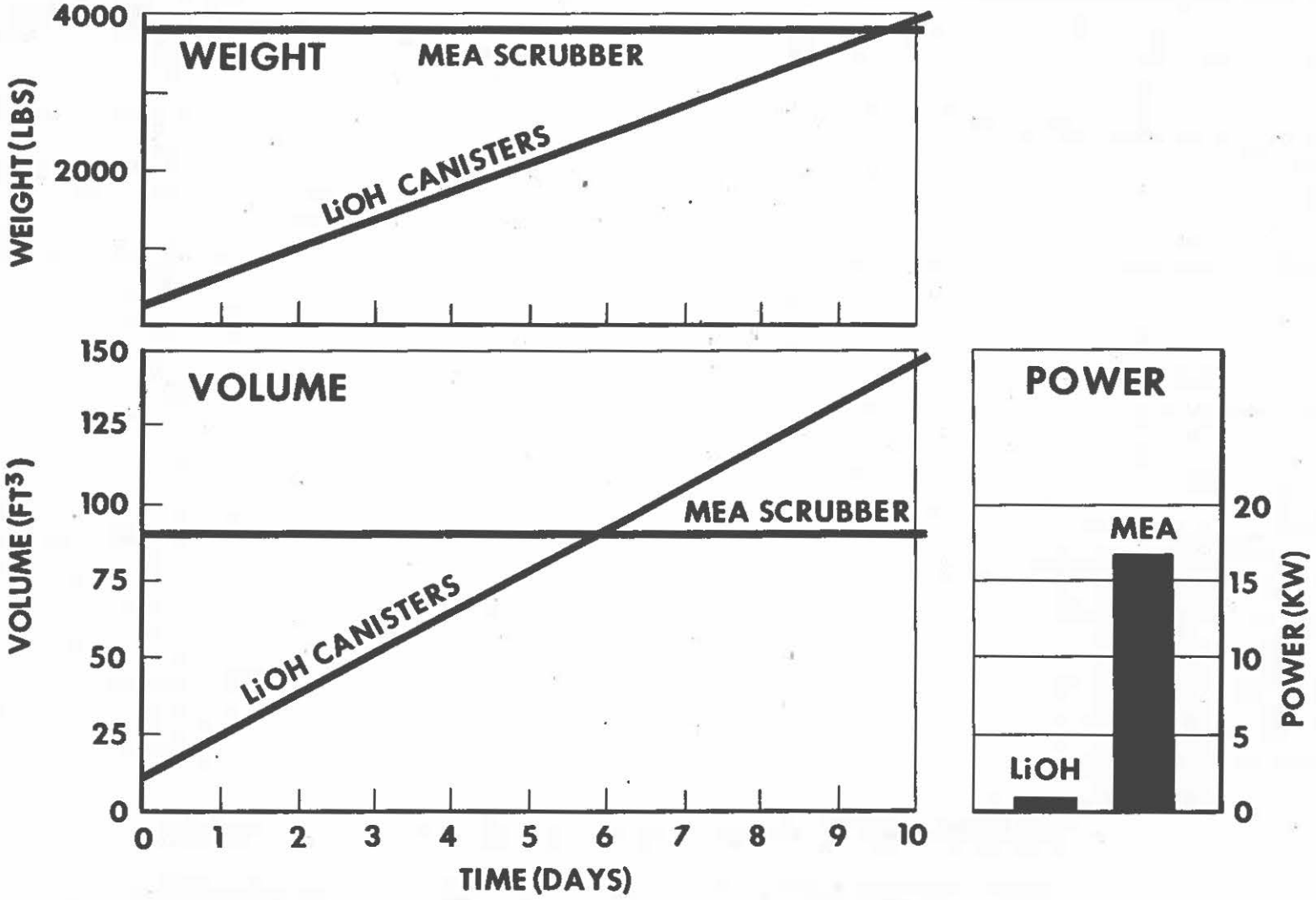


FIGURE 1-2

SECTION 2 - OXYGEN SUPPLY

201. ELECTROLYTIC OXYGEN GENERATOR (MONOPOLAR)

1. Introduction

The first operational submarine electrolytic oxygen generator is the high-pressure, monopolar type built by the M. H. Treadwell Company. It is the only one qualified for service, though other types are currently in various stages of development.

This generator was conceived in 1953 when it was established that the nuclear submarine with extremely long submergence periods would become a reality. At that time, three general methods for making oxygen were available; air distillation, chemicals and electrolysis. The first method, while the most efficient, was not practical due to the lack of air in the submarine; and the second was considered unattractive since it made the submarine contingent upon logistic support for this vital material. The third method, production of oxygen and by-product hydrogen, by electrolyzing distilled water was selected as the ideal method since the two required materials, water and electric power, are readily available on nuclear submarines.

The translation of the selected method into seagoing hardware was the next step. No electrolytic oxygen generators built commercially anywhere in the world were adaptable to submarine use. Their common failings were lack of shock resistance and inability to operate safely under ship's motion. Of equal importance was the fact that all such generators operated at

atmospheric pressure and would require a compressor in order to discharge the by-product hydrogen overboard. At the time this work was begun the state of the art of hydrogen compressors was in its primitive stage, and the available machines were either reciprocating types which leaked profusely at seals and packing or foreign made metal diaphragm machines which were susceptible to frequent diaphragm failures. The former type presented the possibility of introduction of hydrogen into the submarine, a situation which could not be accepted. The latter compressors, while suitable in general principle, were considered so unreliable as to rule out all known models. The approach to hydrogen disposal resolved itself into two possibilities, generation of gases at high pressure or accompanying the generator development with the parallel development of a reliable diaphragm compressor. High pressure electrolysis, while only a laboratory technique at the time, was selected since it presented bonus advantages of a quiet overboard discharge and the ability to recharge oxygen flasks which will probably be carried as a short duration emergency supply.

2. General Description

The monopolar generator (Figure 2-1)is a completely integrated unit which is, in fact, a miniaturized chemical plant. It contains all components necessary in the generation of oxygen and requires only external services as follows:

a. Electric Power - 440 volt, 3 phase, 60 cycle.

b. Distilled Water - 3 gph maximum
1 - 1.4 gph continuous
(depending on operating capacity)

c. Cooling Water - 50 gpm sea water.

d. Control Air - 8-12 SCFM @ 85 PSIG.

e. Nitrogen - 200 standard cubic feet at 1800 PSI minimum per operational cycle.

The generator operates as an unattended unit, is protected by fifty-six safety devices and will shutdown and blanket itself with nitrogen at the occurrence of any malfunction. Operator attention is normally only required during startup and in the final stages of shutdown.

The major component in the process employed in the generator is the electrolytic cell (Figure 2-2). There are 16 of these cells connected in series in a generator. The cylindrical shell is the cell anode, and the wire screen cylindrical element located in the center of the shell and supported from the cell head is the cathode. Both electrodes are nickel plated and the cathode is wrapped with an asbestos diaphragm material which prevents the intermixing of the hydrogen (generated at the cathode) and oxygen (generated at the anode). Each cell also contains a four-point level sensing probe. The probe's lower point is a low level alarm, the two middle points open and close a valve as water is required by the cell, and the upper point is a high level alarm. This cell

when filled with electrolyte (30% KOH) to the desired level and supplied with 750-1050 amperes at 3 volts produces 5.5-7.5 SCFH of oxygen and twice that amount of hydrogen. The chemical reaction involved is shown as

$$2H_2O + e \xrightarrow{KOH} 2H_2 + O_2$$

Figure 2-3 shows a greatly simplified flowsheet for the generator. The generated gases are removed from the cell through the head, and the total system pressure of 3000 PSIG is maintained by a pressure control valve in the oxygen stream. Hydrogen stream pressure must be maintained within ±0.2" water column pressure of the oxygen pressure or the cell will behave like a U-tube manometer, and the level within the cathode will be higher or lower than that surrounding the cathode. If this occurs to an extreme degree, the hydrogen and oxygen will mix resulting in explosive mixtures. To prevent this occurrence, the hydrogen pressure is regulated to ±0.2" water column by means of a pneumatically activated differential pressure controller which senses oxygen pressure and regulates a hydrogen control valve accordingly.

All other components of the monopolar generator are dedicated to supplying the cells with their services and insuring continuous and safe performance of the generator.

3. Operating Experience

Due to the inherent dangers of this electrolytic process, and the fact that hydrogen, the dangers of which are well known to submariners, was to be generated, the generator development was

conducted under the premise that the shipboard prototype must be safe, reliable and must undergo extensive land-based tests before it would be considered for shipboard installation. Significant events in the achievement of these goals are as follows:

a. A laboratory breadboard model consisting of four cells was built and placed in operation at the M. H. Treadwell Company plant. During the early testing a minor explosion occurred in the cells causing piping ruptures and the derangement of internal parts of the cells. An investigation of the explosion yielded two possible explanations of what had happened. One was that a short developed between two wires in the probe, which was a crude affair by present standards, and permitted a low level to develop in a cell without shutting the unit down. This resulted in gas mixing and the ensuing explosion. The second explanation is that the low level was permitted to occur because considerable foaming occurred upon start-up and that, while the level fell, the probe point was in the foam. No shutdown would have occurred in this instance since the foam would appear to the probe to be liquid.

Both of these situations were corrected by improving the probe design and by instituting defoaming procedures for assembled generating plants. The latter procedure removes all foam producing agents from the cell and has completely eliminated the foaming phenomena.

One noteworthy observation of the explosion was that the cells withstood it while the connected piping failed. This indicated that even if an explosion did occur the cells would not

fragment and that the only damage would be distended piping and caustic spray.

b. Following the explosion, the breadboard generator, now composed of two cells, was put through a 30-day continuous run without incident. The cells in this instance were installed on a test stand which was frequently actuated to simulate ship's motion. The motion had no effect on performance. During this period a separate cell was shock tested and came through without damage.

c. The principles of the breadboard were expanded and translated into the first submarine oxygen generator which was completed in mid-1958. This generator was tested extensively and every control and safety device was carefully tested to insure proper and safe performance. Approximately 587 hours of operating time was logged on the generator including continuous runs of 11 days.

d. The first two generators were then tested at U.S. Naval Engineering Experiment Station as reported in reference (b). A total of about 3000 hours of operating time were logged on these units, although continuous runs of only 15 days were achieved. The short duration of the runs were caused primarily by distilled water system difficulties.

During the U.S. Naval Engineering Experiment Station runs, as in Treadwell's breadboard and prototype runs, attempts were made to test all safety devices by simulating each dangerous condition. The equipment coped safely with each situation.

e. Shipboard operation of the monopolar generators began almost simultaneously in USS GEORGE WASHINGTON (SSB(N)598), USS PATRICK HENRY (SSB(N)599), and USS NAUTILUS (SS(N)571). Various malfunctions arose and were corrected, but some major difficulties over and above the routine malfunctioning were experienced. They are summarized as follows:

(1) Damage to Controls by Sea Water

This first shipboard casualty was caused by water backing into the ship's 100 PSIG air system via the ship's whistle during a deep dive. This water ultimately found its way into the oxygen generator pneumatic controls creating such damage as to require replacement of the pneumatic control cubicle and cleaning of all air lines. Future recurrences of this type have been avoided by provision of a control air compressor for the generator and by taking the standby air supply from a ship's air system which has no connection to the sea.

(2) Contamination of Nitrogen with Oil

Four instances of pressurizing the generators with nitrogen containing oil or Cellulube were encountered. The contaminants were introduced via the missile nitrogen systems and

necessitated the replacement of all cells and gas piping on each occasion. Nitrogen systems in the ships were then modified to remove oil contributing sources and strict cleaning procedures were designated for nitrogen systems.

(3) Hydrogen Detonation on USS PATRICK HENRY

There are two drain collecting containers installed under the generator's pneumatic control cubicle aboard ship. These containers provide a convenient and safe way by which moisture traps in the hydrogen and oxygen lines in the generator (Figure 2-3) can be drained. During the draining of the traps, liquid which was carried out of the cells and some small amounts of gas enter the collecting containers. The liquid remains in the container and the gas is vented via a line off the top of the container. On the occasion of this accident, the hydrogen trap drain valve was inadvertently opened wide permitting a relatively large volume of hydrogen to enter the collecting container which in this case had been improperly re-assembled after it had been removed for draining. The hydrogen, instead of proceeding through the vent line, leaked through the container lid and upward into the pneumatic cubicle where it was detonated by an arcing contactor. Corrective action related to this accident was replacement of the containers by all welded ones having drain valves for removal of water.

(4) Dilution of Electrolyte

It has been found that dilution of the electrolyte in the cells occurs after a number of shutdowns. The dilution

shows up as increased cell voltages caused by the higher resistance of the electrolyte. No fixed dilution rate can be predicted since the amount of electrolyte lost from the cells is a function of both the number of shutdown operations and the proficiency of the operating personnel. A maximum cell voltage of 3.5 volts has been established since any higher voltage could result in damage to the nickel plating in the cells. When that value is exceeded, the generator must be secured until the electrolyte can be replenished.

Methods whereby deficient electrolyte can be reconstituted during a cruise have been investigated, but have not been found to be practical. The solution to the problem will be the provision of plastic bottles into which diluted electrolyte will be drawn and a number of similar bottles each containing a cell charge of 30% caustic solution. Instrument air will be used to extract electrolyte from a cell by means of an air injector and new electrolyte will be forced into the empty cell by air pressure.

(5) Distilled Water System Unreliability

Repeated failures of the distilled water pump by-pass valve (PCV-D-103) and pressure transmitter (PT-D-103) have been encountered during early test phases and shipboard operations. Extensive investigations were conducted into improving the reliability of this circuit of the generator and reliable replacements have been found and are being incorporated into new units and backfitted into installed generators. These changes consist of replacing PCV-D-103 with a Grove Regulator and Valve Company "Mitey Mite" Regulator and

PT-D-103 with a Midwest Gage Company pressure transmitter. This combination has been extensively shop-tested and will greatly increase system reliability. (See Addendum "A")

(6) Gas Analyzer Piping Plugging

Repeated instances of this plugging are due to carryover of caustic and moisture into the analyzer piping circuits. De-misters are being fabricated for all units and will be backfit. Laboratory tests of the de-misters indicate that they will greatly minimize this problem.

(7) Gas Analyzer Piping Leaks

Suspicions of leaks in the portion of analyzer circuits downstream of the flowmeters have been reported. If such occurs, it must, of course, be repaired. In order to check that the entire gas sample flow is going through the analyzer head, flowmeters provided as repair parts for the ones installed should be temporarily connected to the discharge ports of the four-way valves and flows upstream and downstream of the analyzer heads should be compared for an indication of any leakage.

(8) Differential Pressure Indicator Fluctuations

A fluctuating differential pressure is observed when the ship is in motion. This is due to the wide difference in densities of hydrogen and oxygen and the changing relative vertical distance between the gas headers and the differential pressure transmitter under ship's motion. With the generator level, the hydrogen and oxygen headers are at nearly the same elevation as the

transmitter, and hydrogen pressure is kept within ±0.2 inch water column pressure of the oxygen pressure. When the submarine rolls, the gas headers become higher or lower than the transmitter and the weight of 3000 PSI oxygen adds or detracts a few inches of water column pressure from the oxygen side of the transmitter and causes the differential pressure indication to swing in response to the ship's roll. This action is a characteristic of this type of differential pressure control instruments and has been damped as much as possible so that it does not cause generator shutdown.

(9) "Black Deposits" in Gas Lines

Great concern has been expressed over finding black, slippery deposits in the gas piping. These deposits slightly resemble oil, and therefore, have caused operating personnel to permanently secure the generators involved until the problem has been explained. The deposits are found in all generators which have been operated and are composed of nickel compounds and crystallized caustic. The fact that nickel is involved is not indicative of destruction of the plating, but is due to the removal of excess nickel which is loosely held to the surface of the plating proper. The appearance of this substance is not an indication of a dangerous situation.

4. Future Developments

a. Noise Reduction

While the generator was not designed with any noise specifications in mind, it became necessary to make it fit the noise

requirements of the SSB(N)608 Class. Tests performed by U.S. Naval Engineering Experiment Station showed that structureborne noise was within acceptable limits, but that airborne limits were exceeded. A study of the noise characteristics showed that the major noise contributor was the rectifier cooling fan, and that the airborne noise could be brought within limits by the addition of noise hoods over the openings on the cell and rectifier side of the generator and by applying sound damping material on the inside of the generator cover plates. Generators furnished for SSB(N)608 and all subsequent submarines will have these additions.

b. Technical Manual

The present technical manual (NAVSHIPS 323-0045) was prepared before any operating experience with the generators had been accumulated. It is inadequate in the areas of trouble-shooting and maintenance and does not cover many of the difficulties so far encountered. A rewrite of the manual is in progress and revised copies should be shipped to all ships having generators by 1 October 1961.

c. Increased Oxygen Capacity

The basic generator was designed conservatively in order to provide a margin to cover any unexpected results arising in the transition from laboratory breadboard to shipboard hardware. The design was reviewed, and tests were conducted to determine the feasibility of increasing the oxygen capacity from 75 SCFH to a figure more closely approximateing the average oxygen consumption rate for an SSB(N). The only equipment modification required to

accomplish an increase to 120 SCFH was found to be a rectifier with a greater output (1050 amps instead of 750 amps). A prototype rectifier which will replace the original rectifier and require no more space was built, installed in a generator, and tested. A twenty-seven day uninterrupted run of this generator clearly demonstrated that a continuous capacity of 120 SCFH can be maintained with cooling water not in excess of 65°F. Restrictions of the cooling circuit make operation at increased capacity impossible in 65° - 85°F sea water. Rather than attempt to revise the cooling system, which would be a major change materially increasing the space requirements of the generator, it was decided that cooling would be left as is and that the operator would have to reduce the current to the cells when operating in sea water exceeding 65°F.

New rectifier cubicles are being procured for all generators and will be made available on the basis of two per month after 1 July 1961. It is intended that the replacement will be made by ship's force with M. H. Treadwell Company supervision.

5. References

a. Technical Manual - NAVSHIPS 323-0045 - "Electrolytic Oxygen Generator"

b. "Evaluation Report of M. H. Treadwell Company Electrolytic Oxygen Generator" - U.S. Naval Engineering Experiment Station Evaluation Report 610405B of 11 August 1960.

FIGURES

2-1. Monopolar Oxygen Generator

2-2. Electrolytic Cell

2-3. Simplified Flow Sheet - Monopolar Oxygen Generator

ADDENDUM

A. Since the Barton element of pressure transmitter (PT-D-103) has been the source of most of the troubles in the water system and that transmitter is only used for indicating purposes, unnecessary repair and maintenance work can be avoided by discontinuing the use of PT-D-103 until the MIDWEST transmitter is made available. To accomplish this, the MOORE Model 12CH22 transmitters should be blocked off by closing the needle valves in the high pressure housing. Replacement of transmitters will begin in June 1961.

202. CHLORATE CANDLES

1. Introduction

Chlorate candles are a non-regenerative chemical means of storing oxygen, analogous to hydrogen peroxide (H_2O_2), potassium superoxide (KO_2), etc., and competitive with physical systems such as compressed gas, liquid oxygen (LOX), etc.. Table 2-1 compares various oxygen sources that have been used or considered for submarines, but it should be noted that values given are exclusive of container and do not take into account whether stowage is inside or outside the pressure hull. However, in spite of these limitations, the table shows that chlorate candles are an efficient method of storing oxygen in a minimum volume.

Candles were first evaluated for use in U.S. submarines in 1945 in tests conducted aboard USS SAILFISH (*1) as the result of development work by Naval Research Laboratory (NRL), Mine Safety Appliances Company, and Oldbury Electro-Chemical Company. (*2, 3) These candles were greatly improved versions of types developed by foreign countries (Germany, Japan) and the tests demonstrated the suitability of this method of stowing oxygen in submarines. However, because no operational need existed at that time, further development was suspended until 1958 when work was started which has led to the present operational

(*1) Refers to References at end of text.

system. Although chlorate candles are currently used in submarines by several foreign navies, (e.g. France, Great Britain) the U.S. system is superior in terms of oxygen purity and stowage volume requirements and comparable in cost per ft^3 of oxygen.

For nuclear powered submarines, candles are a convenient, interim oxygen system for use while continuous generators are being developed and installed in all ships. The primary use is to extend submerged endurance beyond that permitted by installed oxygen banks. Because of the system's simplicity and flexibility, candles (combined with lithium hydroxide) offer a rapid solution to atmosphere control on battery powered submarines in the event periods of submerged operation are increased.

2. Technical Description

The reaction which releases oxygen when a candle is burned is as follows:

$$NaClO_3 + Fe \xrightarrow{BaO_2} NaCl + Fe_xO_y + O_2 + \triangle$$

where: $NaClO_3$ = sodium chlorate

Fe = iron

BaO_2 = barium peroxide

NaCl = sodium chloride (table salt)

Fe_xO_y = Various iron oxides (Feo, Fe_2O_3, etc)

$\triangle$ = Heat

The basic process is the thermal decomposition of sodium chlorate to salt and oxygen. However, to eliminate the need for an external source of heat, iron (around 5% by weight) is added which combines with some of the oxygen to produce enough heat for the process to be self sustaining. Barium peroxide is added to remove undesirable chlorine by-products. For present size candles, around 9500 BTU/candle are produced which corresponds to about 3/4 ton of air conditioning when candles are burned at the rate of one per hour.

Present candles are produced by Mine Safety Appliances Company, Pittsburgh, Pennsylvania and have the following characteristics:

size = 6 1/4" diam. x 11 3/8" long

weight = 26.2 lbs (average)

O_2 $\leq$ 116 SCF

Burning time = 50 $\pm$ 5 minutes

Contaminants in O_2 (average values)

Chlorine (Cl_2) $\leq$ 1 ppm

Carbon monoxide (CO) $\leq$ 1 ppm

Water Vapor (H_2O) $\leq$ 54 grains/lb O_2 (54° F dew point)

Compared to other methods of stowing oxygen, candles are relatively safe. The chief danger lies in contaminating them with combustible material (grease, oil, etc.) prior to ignition.(*4) While they will not spontaneously ignite, subsequent normal

ignition will probably cause a violent combustion, as would be expected whenever hot oxygen and combustible material are brought together. Uncontrolled or undesired burning of candles can be readily stopped by quenching with water as has been demonstrated in laboratory tests. (*5)

The candle system is simple and reliable and consists of igniting the top one of two candles in the standard furnace by means of a chemical match. (*4, 6) Oxygen exhausts through a washable salt filter and no attention is required during the burning of the two candle charge. Disposal of the spent "clinkers" is normally accomplished through the GDU (garbage disposal unit) and clinkers have proved useful as weights for garbage bags. Salt filters are periodically washed with fresh water and reused. Chlorine filters are no longer required.

3. Operational Experience

The first operational use of candles in submarines was by USS SEAWOLF (SS(N)575) during her record-breaking 60 day submergence in 1958. The candles used were an early type which were smaller than present design and oxygen evolved by them contained significant amounts of chlorine. A jury rig chlorine scrubber (using photographis "hypo") (*7) was used on this cruise and let to development of a chlorine filter (using hopcalite) for subsequent furnaces. Various improvements in candle formulations and furnace designs have been evaluated at

sea in Bureau tests in USS SEALWOLF (*8), USS SKATE (SS(N)578)(*9), and USS TRITON (SS(N)586)(*10). USS SKATE tests demonstrated that chlorine filters are not required with current candles.

The candle system has now had extensive operational use in nuclear powered submarines and has proved to be simple and reliable for the purpose of augmenting installed oxygen banks. The two major drawbacks (aside from logistic problems) have been cost and stowage. The cost of oxygen from candles has been decreasing steadily and the Bureau is attempting to achieve further sizeable reductions by manufacturing process improvements and the development of procurement competition. Stowage remains a problem but the use of auxilliary ballast tanks in some USS SKATE Class submarines and the use of a fresh water tank in USS TRITON have appeared to be practical approaches.

4. Stock Numbers

Candles and furnaces are available from Submarine and Reactor Parts Supply Office (SUBARPSO) as follows:

Candle, oxygen large	PF4470-713-2714
Furnace, oxygen candle	PR4470-713-2707

REFERENCES AND BIBLIOGRAPHY

1. Miller, R.R., et al, "Experimental Control of CO_2 and Oxygen Concentrations Aboard the USS SAILFISH", NRL Report P-2665 dated October 1945.

2. Schechter, W.H., et al, "Chlorate Candles as a Source of Oxygen", IND ENG CHEM 42, 2348-53, 1950

3. Oxygen Research (Summary Technical Report of Division 11, NDRC), Columbia University Press (1946).

4. BUSHIPS Instruction 9230.11, Ser 649B-1834 of 25 July 1960 with Change 1, Ser 649B-2664 of 6 January 1961

5. NRL Film Report on Candle Safety (in preparation)

6. "Instruction Manual for Sodium Chlorate Candles and Furnace Assembly", MSA Research Corp. publication dated 20 Jan 1960

7. Oblinger, L.P., ENC(SS), "Atmosphere Control Information Report" (in preparation)

8. Bureau of Ships Report on Travel (CONFIDENTIAL), Ser 649B-045 of 1 December 1958

9. BUSHIPS Report on Travel SS(N) 578, Ser 649B-1619 of 21 June 1960

10. BUSHIPS Report on Travel SS(N)586, Ser 649B-2761 of 5 November 1960

TABLE 2 - 1

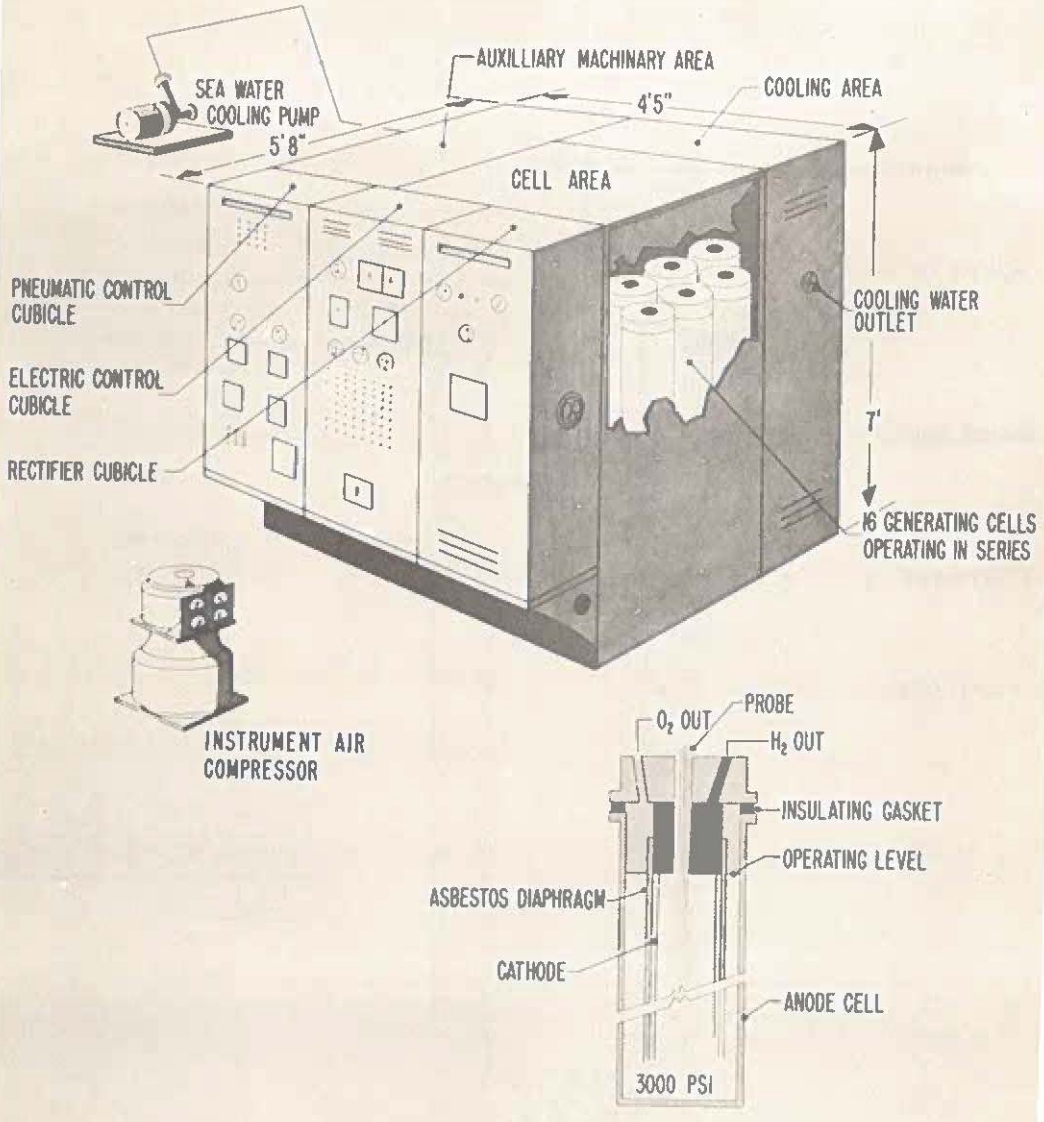
NON-REGENERATIVE OXYGEN SOURCES

Material	Oxygen Content [1]		
	Wt. %	lb/ft^3	scf/ft^3
Potassium superoxide (KO_2)[2]	34	14	170
O_2 at 3000 psig and 70°F	100	17	200
Hydrogen peroxide (90% H_2O_2)	42	37	450
Chlorate Candle	35	49	570
Liquid O_2(LOX)	100	71	835

1 exclusive of container

2 granular form as used in OBAs

MONOPOLAR GENERATOR



CHARACTERISTICS:

OXYGEN CAPACITY	120 SCFH, 3000 PSI
VOLUME	175 FT^3
WEIGHT	15,500 LBS

SERVICE REQUIREMENTS:

ELECTRICAL	70 KW, 440 V, 3 PH, 60 CY.
INSTRUMENT AIR	10 SCFH AT 55 PSIG
NITROGEN (OIL FREE)	230 SCF/CYCLE
DISTILLED WATER	1.5 G.P.H.
COOLING WATER	50 G.P.M. SEA WATER

FIGURE 2-1

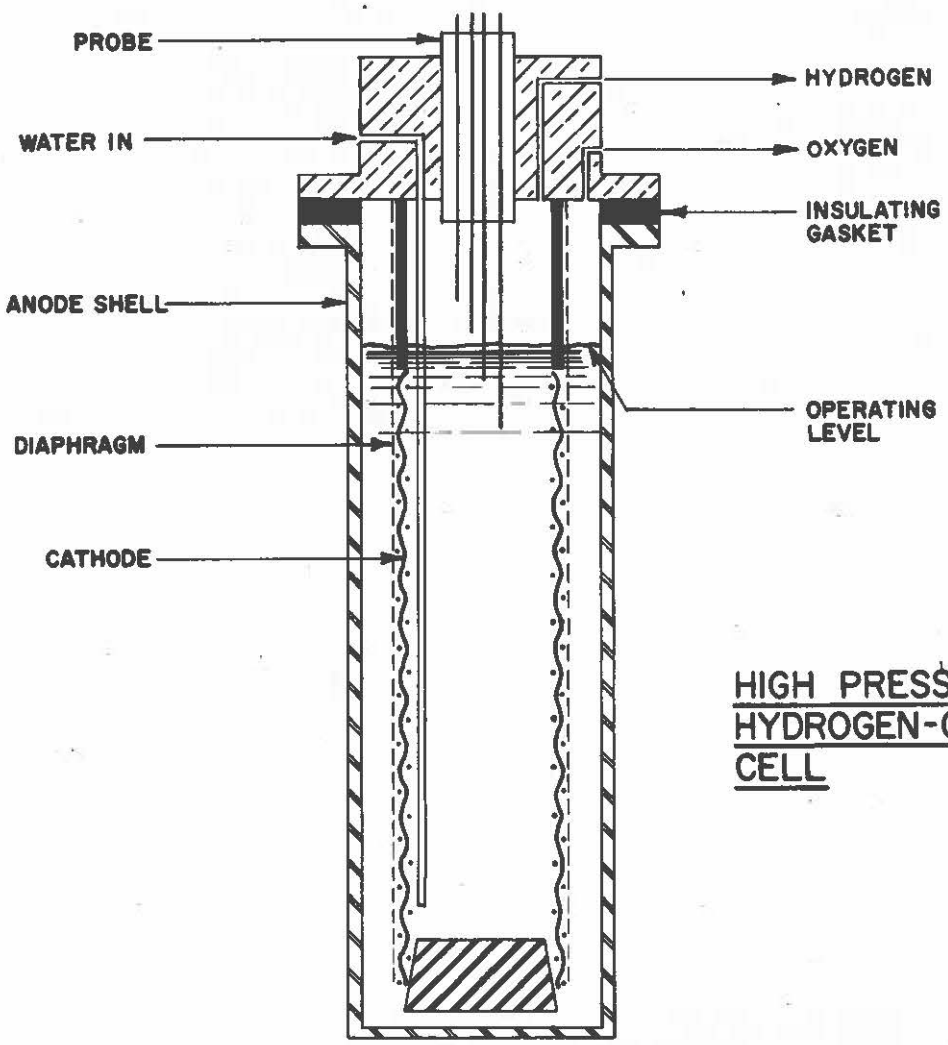
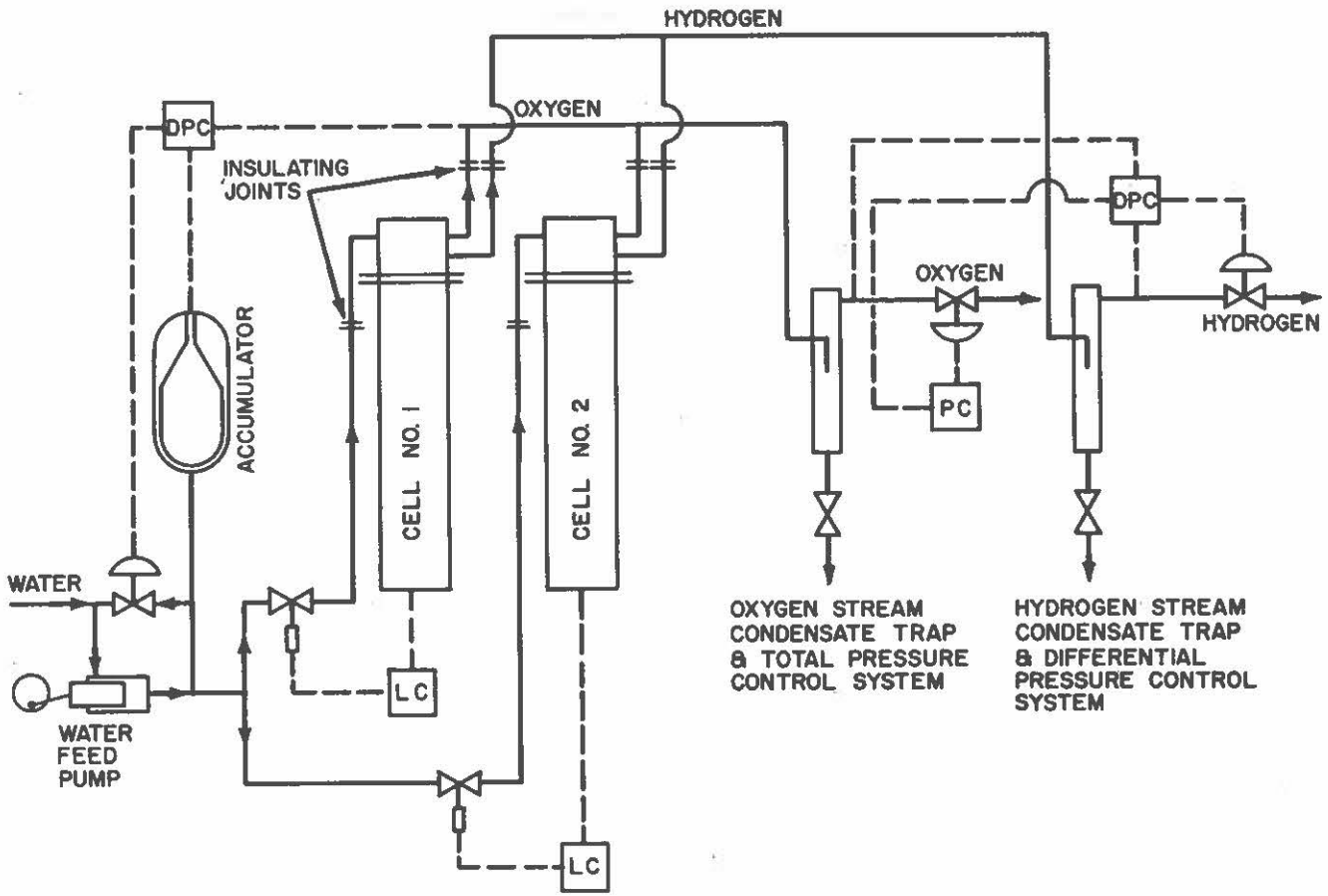

PROBE
WATER IN
ANODE SHELL
DIAPHRAGM
CATHODE
HYDROGEN
OXYGEN
INSULATING GASKET
OPERATING LEVEL
HIGH PRESSURE HYDROGEN-OXYGEN CELL

FIGURE 2-2



FLOW SHEET

HIGH PRESSURE ELECTROLYTIC OXYGEN GENERATOR

FIGURE 2-3

SECTION 3

CARBON DIOXIDE REMOVAL

PART I - Carbon Dioxide Removal by Regenerative Processes

301 Introduction.

Continuous removal of carbon dioxide became necessary when nuclear power made it possible for submarines to operate submerged for indefinite periods of time. Fortunately there was a considerable body of experience which made possible the rapid development of CO_2 removal equipment. Since the time of the first nuclear submarine, much effort has been expended to find better CO_2 removal processes and to improve on the existing CO_2 removal process. References 3-1B-1, 3-1B-3, 3-R-1, 3-R-2, 3-R-3, 3-R-4, 3-R-5, 3-R-6, 3-R-7, 3-R-8, 3-R-9, 3-R-10, 3-R-11, 3-R-12 give information of general historical interest.

302 Early efforts were concerned with many different types of processes. These included:

a. Systems using several different liquid absorbents for CO_2 removal. About 300 different liquid absorbents were studied. Notable in the absorbents studied were diethanolamine, diethylene glycolamine, methyl diethanolamine, alkazid, and potassium carbonate.

b. A system for condensing CO_2 as a solid on a refrigerated surface.

c. Systems involving adsorbing the carbon dioxide on solid adsorbents such as silica gel, charcoal, and a proprietary product called Molecular Sieves.

d. Systems involving absorbing the carbon dioxide in sea water. Each of these processes was extensively investigated and none was found to be competitive with the system now in use after review of the space required, power, or reliability. Investigation of the freeze out system and the adsorbent system are continuing.

303 Principles of Operation.

The following discussion is for the purpose of explaining CO_2 scrubber performance in general terms. It is intended to provide a quick understanding of CO_2 scrubbers and their operation; not to give operating details, since these are thoroughly covered in the applicable instruction book.

304 Working Fluid.

The working fluid in all CO_2 scrubbers in use today is a mixture of monoethanolamine and water. The chemical, monoethanolamine (mŏn' ō · ĕth' ă nōl · ă mēn') is a common organic chemical widely used in industry for absorbing carbon dioxide. When pure, the chemical is water white and practically odorless. It gradually deteriorates in storage and gives off ammonia which has a strong odor. As a result of the deterioration, monoethanolamine,

from a practical point of view, does have an odor. In speaking of monoethanolamine the name is usually abreviated to "MEA" or "amine". The abbreviation MEA is preferred since the term amine could be applied to any of several chemical compounds whereas the term MEA is almost never used for any other chemical except monoethanolamine. The MEA-water mixture used in a CO_2 scrubber contains about 25 percent of MEA. The strength of the solution is determined using a test kit provided with each scrubber. The results of the test are expressed in terms of "normality". A 4.0 normal solution contains 24 percent of MEA. The instruction book requires that the amine normality be kept between 4.0 normal and 5.0 normal.

305 MEA is alkaline and therefore has an affinity for carbon dioxide which is acid. At elevated temperatures, amine loses its alkaline characteristics and the carbon dioxide can be separated from it.

306 Absorption System.

The performance of a CO_2 scrubber can best be understood by reference to the simplified flow diagram, Figure 3-1. A blower picks up atmospheric air from the submarine and forces it through the absorber tower. The air passes over a bed of "packing" in the absorber. The packing is kept continuously wet by the MEA-water solution which is circulated by means of the recycle pump. The packing in some scrubbers is stainless steel lathe

turnings. In other scrubbers, the packing consists of short pieces of thin wall pipe 1/2 inch in diameter dumped into the absorber. The only function of the packing is to provide a large amount of surface so that the air can be effectively contacted by the liquid. In the packing, the CO_2 from the air transfers itself to the amine. In other words, it dissolves in the liquid. Air and liquid from the packing pass through the holes in the packing support in the lower end of the absorber. The liquid drops to the sump; the air passes out of the absorber. After the air leaves the absorber, it passes through a clean-up system (not shown on figure 3-1) and then out into compartment or into the ship's ventilation system.

307 Regeneration System.

In the absorber, the amine solution is continously picking up CO_2. If there were no regeneration, the solution would soon become saturated and lose its ability to pick up CO_2. A small stream of the amine solution is continuously pumped from the absorber to the stripper tower where the amine is regenerated. That is, the CO_2 is boiled out of the solution. The CO_2 from the stripper is cooled in the condenser on the top of the stripper tower and then goes to the sea by way of the CO_2 compressor. The amine solution in going from the absorber to the stripper is heated in the main heat exchanger. The regenerated amine solution

is cooled in the main heat exchanger as it flows from the stripper to the absorber.

308 Scrubber Capacity.

The CO_2 scrubber installation, in all ships which have two scrubbers, is designed with the object of having one unit serve as a spare. That is, one unit is designed to be able to hold the CO_2 concentration of the ship below 1.0 percent during normal expected load conditions and below 1.5 percent under peak load conditions. This design goal is achieved only if the scrubber is kept in good operating condition, if operated so as to maintain maximum performance, if the ships ventilation system is rigged to assure adequate air flow to the scrubber, and if the number of persons aboard is no greater that that number for which the system was designed. The capacity of a scrubber, (usually expressed in pounds per hour) is dependent on many factors. Some of the factors and how they affect performance are listed below:

a. CO_2 concentration of entering air. The higher the CO_2 concentration the higher the capacity. The capacity is roughly proportional to the concentration. That is, doubling the CO_2 concentration approximately doubles the capacity. (See Figure 3-3)

b. Stripping rate. A stripping rate less than the maximum possible gives the best performance. The optimum stripping rate is about 45 gallons per hour. The optimum

stripping rate is different for different conditions (sea water temperature, air temperature, heat exchanger condition, CO_2 concentration, amine normality and heater setting). Since these conditions change with ship operating conditions, it is not possible to preset the scrubbers to give the maximum output. The operator can, by adjusting the stripping rate (read on the MEA flowmeter), obtain the best possible stripping rate. The stripping rate during normal operation should never be adjusted so low that the temperature of the CO_2 coming from the condenser rises above 105 degrees.

c. Heater setting. Two heater settings are practical for normal scrubber operation. These are 11.5KW and 9.2KW. If the stripping rate is adjusted to give the maximum CO_2 removal rate, there is only a slight difference between the capacity of a scrubber at the two heat input settings. See figure 3-4.

d. Amine normality. The higher the normality of the solution the greater the capacity of the scrubber. Unfortunately, increasing the normality increases the rate of deterioration of the amine and the rate of consumption of acid and the odor of the treated air. Normality should never be allowed to go above 5.0.

e. Air Flow rate. The air flow rate is, of course, dependent upon the design of the scrubber. Table 3-1 shows the design air flow of scrubbers. The air flow through a scrubber of

a given design is affected by the temperature of the air, the temperature of the absorber, the condition of the blower intake screen, the resistance imposed by any external ducts, and the condition of the blower. Generally speaking, it is highly desirable to have the maximum practical flow through the scrubber since this increases the capacity, reduces the absorber temperature, and reduces the concentration of ammonia in the treated air.

309 CO_2 Scrubber Models.

All CO_2 scrubbers in use today are of the Mare Island design or variations from that design. They all use a flow pattern like that shown in figure 3-1. Generally speaking the major components are arranged as shown in figure 3-2. Table 3-1 gives information regarding the usage of the individual scrubbers, the manufacturer, the air flow, the applicable instruction book number, and the assembly drawing. The assembly drawing is the key drawing for finding other detail drawings of any particular scrubber. There are minor differences between one CO_2 scrubber and another. There are also major differences which will be discussed below.

310 In the group of scrubbers from 1-31 there were only minor differences, from the operational point of view. The principal equipment differences were in regard to the recycle pump, the packing material in the absorber, the brand of electric motor,

and the piping arrangement. Scrubbers beginning with unit 32 were modified to process 215 cubic feet per minute of air. Units 32 and 33, and those beyond 46 were built to stringent noise standards and are distinctly different from the earlier models in several respects. The major difference between the noise-modified units and the "noisy" units were:

a. Components mounted on rubber whereever possible.

b. Paxton centrifugal blower used instead of a Roots-Connersville type blower.

c. Compressor, stripper pump, SW pump and FW pump operated at lower speed.

d. Compressor unloader removed.

e. Noise tested bearings used throughout.

f. Components dynamically balanced to a high degree.

311 Current CO_2 Scrubber Production.

Units starting with number 70 will be built to two designs which will be even quieter than any of those which were produced earlier. The first of these new designs is based upon the earlier model scrubbers. In this modification, all rotating components will be supported by a framework which will be suspended from the main support platform by the use of rubber mounts. This modification is being developed by Girdler Corporation. As stated in the footnotes of table 3-1 the external connections and mounting for the Girdler modification will be the same as for earlier model scrubbers.

312 Mare Island is developing an entirely new CO_2 scrubber. The flow cycle will be much like that shown in figure 3.1 but the arrangement and selection of components will be greatly different. By present plans scrubbers built to this new design will first appear on ships bearing hull numbers 625 and 626.

313 Operating Experience.

An effort is made to reflect in the CO_2 scrubber operating manuals all things learned by experience with CO_2 scrubbers. It is the function of this section to restate and amplify existing instructions and to furnish guidance information not yet incorporated into instructions or in the technical manual. It is not the purpose of this section to eliminate the need for issuance of Bureau of Ships instructions or revisions to technical manuals.

313a Shaft Seals on SW and FW pumps.

In the past, considerable trouble has been encountered with seals on salt water and fresh water pumps on CO_2 scrubbers. The seals have failed in service due to corrosion of the seal shell. This corrosion started at a point where a lip had been formed on the shell of the seal. It has been found by test that the seal shell, if made from type 316 stainless steel instead of type 303 stainless steel, will last longer in service. An instruction is being issued calling for use of the new seal. The stock number of the new seal is P5330-613-3892. The instruction is in Bureau of Ships letter 9380/6 Ser 649C-617

dated 11 April 1961. Reference 3-C-1 described the tests leading to adoption of the new seal.

313B LIMEA CHELATE.

Tests at Mare Island Naval Shipyard have shown that low iron content MEA does not deteriorate as rapidly as ordinary MEA. It was found also that an additive, called a chelating agent, would reduce the rate of deterioration. Arrangements have been made with the Dow Chemical Company to sell a mixture of low iron content MEA and the chelating agent. Reference 3-L-1 gives instructions on the purchase and use of the new mixture. The new mixture is called LIMEA CHELATE MIX 22/1. The ratio 22/1 is the weight ratio of the MEA to the active ingredient of the chelating agent. The new mixture is used almost the same as ordinary MEA is used. When the new mixture is used in a CO_2 scrubber, copper sulfate should not be used as an additive and anti-foam agent should not be used unless there is a clear indication that the amine solution is foaming. The normality of the solution should be kept at about 4.0 when using the new amine mixture.

313c Leakage problems.

The quantity of carbon dioxide separated from the air by a CO_2 scrubber under normal conditions is very small. It is, of course, equal to that produced by the personnel on the ship,

about 12 pounds per hour. A very small hole could leak all the CO_2 that is produced. For this reason, particular pains are taken in producing scrubbers to prevent leaks in the piping and to make sure that valves do not leak. Despite this effort, leaks do develop in the valves in the CO_2 system during the period from the time when the scrubber is produced and the time when the ship personnel have developed operating skill and the ability to recognize presence of leaks. The places where leaks are likely to develop are in the CO_2 back pressure valve, CO_2 compressor valves, CO_2 compressor unloader valve, the stripper relief valve, and in the valves which branch off of the CO_2 lines. A very small amount of hard material can hold the diaphragm operated valves open enough to give trouble. The unloader system in the CO_2 compressor is one of the likely sources of leaks. Since the compressor was installed in early model scrubbers it has been found that the unloader system is unnecessary. On late model scrubbers, the unloader is eliminated. On early model scrubbers the possibility of CO_2 leakage through the unloader can easily be eliminated. To accomplish this remove the two lines which are connected to the unloader body, and provide gas tight closures for the four openings created thereby.

313d MEA Consumption.

The MEA in a scrubber gradually deteriorates. Associated with this deterioration, two undesirable things occur. Ammonia

is given off by the solution, and undesirable chemicals resulting from the decomposition collect in the scrubber working fluid. The ammonia produced in the scrubber is undesirable for two reasons. Part of the ammonia passes through the purifiers and ends up in the product air. The ammonia which remains in the purifiers consumes the acid used in the purifiers. It has been found that the rate of formation of ammonia increases with the age of the solution. With a very old solution the rate of consumption of sodium bisulfate will be quite high. The decomposition products which collect in the amine solution can cause the solution to foam. Also, it is possible, although there is some uncertainty here, that the accumulation of deterioration products can cause the amine solution to fail to function properly even though the operator maintains the correct normality by adding make-up amine.

In view of the above there are several possible reasons why an operator might want to change the amine in a scrubber.

a. Excessive odor.

b. Excessive consumption of amine and acid.

c. Foaming of the amine solution which can not be controlled by the use of reasonable amounts of anti-foam agent.

d. Failure of the scrubber to remove CO_2 at a rate necessary to hold the CO_2 concentration in the ship at a satisfactory level.

e. Difficulty with observing the end point of the normality test.

At the present time the Bureau cannot recommend definite limits on the amount of time which a given charge of amine can remain in a scrubber.

It is possible to list several things which will significantly prolong the "life" of amine.

a. Use LIMEA CHELATE MIX instead of ordinary MEA.

b. Keep the absorber temperature as low as possible.

c. Operate the scrubber at a reduced heat input. Specifically 9.2KW. See paragraph 308c and figure 3.4.

d. Use the lowest possible normality which will provide satisfactory CO_2 removal considering the CO_2 "load" created by the number of persons aboard and by the level of activity of these persons.

e. Turn off the reboiler heaters one hour before shutting down the remainder of the scrubber. The scrubber will continue to remove carbon dioxide for about an hour after the heater elements of the reboiler are turned off. During this period, flow of amine to and from the reboiler should be continued at a greater than normal rate. This will tend to cool the reboiler.

.f. Do not start to operate the scrubber until the CO_2 concentration in the ship has risen to above 1.2 percent.

g. Do not operate the scrubber when the CO_2 concentration is below 0.8 percent.

h. Do whatever is practical to keep the amine from becoming contaminated with traces of iron.

i. Make certain that air flowing to the scrubber does not have a low CO_2 concentration caused by incorrect setting of the controls on the ships air movement system.

j. Rinse out the absorber and stripper with fresh water before adding a new charge.

k. If it is practical to do so, keep the air flowing to the scrubber as cool as possible since this will increase the amount (by weight) of air being processed and also reduce the absorber temperature.

l. Change the amine in CO_2 scrubbers only as often as is considered necessary, based on the difficulties listed in the start of this paragraph.

TABLE 3 - 1

3/24/61

CO_2 Scrubber
Application Data

SHIP		CO_2 SCRUBBER				
HULL NR.	NAME	SER NR.	MANUFACTURER	AIR FLOW (CFM)	INST. BOOK (NAVSHIPS)	ASSEMBLY * DRAWING ABBREV.
SSN571	NAUTILUS	8 & 9	Mare Island	170	323-0017	-771370
SSN575	SEAWOLF	14 & 15	Mare Island	170	323-0039	-1512012
SSN578	SKATE	3 & 4	" "	170	323-0017	-771370
SSN579	SWORDFISH	6 & 7	" "	170	"	"
SSN583	SARGO	10 & 11	" "	170	"	"
SSN584	SEADRAGON	12 & 13	" "	170	"	"
SSN585	SKIPJACK	5	" "	170	"	"
SSN585	SKIPJACK	18	" "	170	323-0039	-1512012
SSN586	TRITON	16,17,19	" "	170	"	"
SSN587	HALIBUT	20 & 21	" "	170	"	"
SSN588	SCAMP	44 & 45	Girdler Corp.	215	323-0051	-1523006
SSN589	SCORPION	24 & 25	Mare Island (Firestone subcontractor)	170	323-0039	-1512012
SSN590	SCULPIN	26 & 27	" "	170	323-0039	"
SSN591	SHARK	28 & 29	" "	170	"	"
SSN592	SNOOK	30 & 31	" "	170	"	"
SSN593	THRESHER	32 &33	" "	215	323-0039**	-1523006**
SSN594	PERMIT	48 &61	Girdler	215	323-0051***	-1524623
SSN595	PLUNGER	46 & 47	"	215	323-0051***	"
SSN596	BARB	49 & 50	"	215	323-0051***	"
SSN597	TULLIBEE	22	Mare Island	170	323-0039	-1512012
SSBN598	GEO. WASH.	34 & 35	" "	215	323-0051	-1523006
SSBN599	PATRICK HENRY	36 & 37	" "	215	"	"
SSBN600	THEO. ROOSEVELT	38 & 39	" "	215	"	"
SSBN601	ROBERT E. LEE	40 & 41	Girdler	215	"	"
SSBN602	ABRAHAM LINCOLN	42 & 43	"	215	"	"
SSN603	POLLACK	62 & 63	"	215	323-0051***	-1525623

SSN604	HADDOCK	70 & -	Girdler	239(est)	323-0051***	-1524623****
SSN605	JACK		"	230(est)	" ***	" ****
SSN606	TINOSA	68 & 69	"	215	" ***	-1524623
SSN607	DACE	51 & 52	"	215	" ***	"
SSBN608	ETHAN ALLEN	53 & 55	"	215	" ***	"
SSBN609	SAM HOUSTON	59 & 60	"	215	" ***	"
SSBN610	THOMAS EDISON	54 & 56	"	215	" ***	"
SSBN611	JOHN MARSHALL	57 & 58	"	215	" ***	"
612-615	---	---	"	230(est)	New	****
SSBN616	LAFAYETTE	64 & 65	"	215	323-0051***	-1524623
SSBN617	ALEX. HAMILTON	----	"	230(est)	New	****
SSBN618	THOMAS JEFFERSON	66 & 67	"	215	323-0051***	-1524623
619-624		----	"	---	New	****
625-626		----	Mare Island	---		Entirely new design
SSBN20-22		----	" "	---	"	" "

* The complete numbers are SSN578-S3806-771370; SS-501-H-1512012; SS-501-H-1523006; SS-501-H-1524623. These drawings refer to related drawings which more fully describe individual scrubbers.

** Drawing and instruction book cover scrubbers as originally furnished. Portsmouth Naval Shipyard is to make drawings showing their noise reduction modifications.

*** Instruction book now covers plants as originally built. The book will be revised by Girdler to cover noise reduction package applied to certain scrubbers.

**** So far as service connections and mounting are concerned units will be identical to earlier units. Internal changes being made will result in lower noise levels.

TABLE 3-2

References

INSTRUCTION BOOKS

CO_2 Scrubbers

3-1B-1 NAVSHIPS - 323-0017, Submarine CO_2 Removal Plant, SS(N)571, SS(N)575, The Girdler Company, NObs 50234, May 1955.

3-1B-2 NAVSHIPS 323-0033, Carbon Dioxide Removal Plant, Units 1 through 13, Mare Island Naval Shipyard, January 1958.

3-1B-3 NAVSHIPS 323-0037, Submarine CO_2 Removal Plant , Girdler Construction Division, Chemetron Corporation, Contract NObs 68231, February 1959. (Covers 5 units)

3-1B-4 NAVSHIPS 323-0038, Carbon Dioxide Removal Plant, Units 34 through 39, Mare Island Naval Shipyard, March 1959, Revised June 1960.

3-1B-5 NAVSHIPS 323-0039, Carbon Dioxide Removal Plant, Units 14 through 33, Mare Island Naval Shipyard, January 1959.

3-1B-6 NAVSHIPS 323-0051, Carbon Dioxide Removal Plant, Units 40 through 70, Girdler Construction Division, Chemetron Corporation, September 1959 (Revision in preparation covering noise modified scrubbers)

CO_2 Compressors

3-C1B-1 NAVSHIPS 349-0601 Instruction Book for 2AP8DS Compressor Westinghouse Air Brake Company.

Positive Displacement Blower

3-C1B-1 NAVSHIPS 341-3405, Maintenance and overhaul Manual for 3, 4, and 6 Cylinder Marine Propulsion Units, General Motors Diesel; Series 71, Detroit Diesel Engine Division. (This manual includes data on assembly of positive displacement type blower used on early model CO_2 scrubbers.)

CORRESPONDENCE

L-1 Bureau of Ships letter 9380/6, Ser 649G-220 of 15 February 1961. Subject: CO_2 Scrubbers, New Amine Mixture For

L-2 Bureau of Ships letter SS(N)575 Ser 649B-2890 of 21 November 1960. Subject: Atmosphereic Habitability tests aboard USS SEAWOLF (SS(N)575); agenda for) (This letter covered, among other thing, scrubber pump seal tests and chelate tests.)

L-3 Bureau of Ships letter 9380/6 Ser 649G-617 dated 11 April 1961. (Recommends adoption of new seal for SW-FW pumps)

REPORTS

The reports listed here are those which may be of value in operating installed CO_2 scrubbers, or evaluating performance, or which are of general historical interest. Other reports which cover developmental tests or comparision between competing processes or competing equipments are available from Code 649G, Bureau of Ships, upon request.

R-1 University of Pennsylvania, Thermo-dynamics Research Laboratory, W.E. Catterall, "Removal of Carbon Dioxide from Submarine Atmospheres by Ethanolamine Scrubbing," S-2 Unit

R-2 A.D. Little, Inc., Cambridge, Massachusetts, Study of Systems for Removal of Carbon Dioxide from Submarine Atmospheres by Direct Cooling, Contract NObs 72156, September 30, 1956.

R-3 A.D. Little, Inc., The Removal of Carbon Dioxide from Submarine Atmospheres, Final Report to Bureau of Ships, Contract NObs 72156, November 26, 1956.

R-4 Ionics Inc., Atmospheric Regeneration Aboard Submarines Using Alkali Metal Higher Oxides, Contract NObs 77048, Final Report, June 1959.

R - 5 Mare Island Naval Shipyard, Industrial Laboratory, "Characteristics of the Mare Island Class SSN-587 CO_2 Scrubber", Report 4731-57, July 16, 1957.

R-6 Mare Island Naval Shipyard, Industrial Laboratory, "Characteristics of the Mare Island CO_2 Scrubber at High Flow", Report 5614-58, August 19, 1958

R-7 Mare Island Naval Shipyard, Industrial Laboratory, "Mare Island CO_2 Scrubber, Effects of Operation at Less Than Maximum Capacity", Report 282-59, February 25, 1959

R-8 Mare Island Naval Shipyard, Industrial Laboratory, "Stabilization of Monoethanolamine with Chelating Agents", Report 7116-59, April 12, 1960

R-9 Mare Island Naval Shipyard, Industrial Laboratory "Removal of Ammonia and Amine From Air Streams By Ion Exchange Resins", Report No. 7516-59, August 9, 1960

R-10 Mare Island Naval Shipyard, Industrial Laboratory, "Chelating Agents in CO_2 Scrubber Operation", Report No. 1211-60, June 3, 1960

R-11 Mare Island Naval Shipyard, Industrial Laboratory, "Thermal Deterioration of Monoethanolamine in Mare Island CO_2 Scrubbers", Report No. 6017-60, December 16, 1960

R-12 Naval Research Laboratory, "The Present Status of Chemical Research in Atmosphere Purification and Control on Nuclear-Powered Submarines, Edited by R.R. Miller and V.R. Piatt, April 21, 1960

TEXTBOOKS

TB-1 Quinn, Elton L. and Jones, Charles L., "Carbon Dioxide", Reinhold Publishing Corporation, 1936

TB-2 Kohl, Arthur L. and Riesenfeld, Fred C., "Gas Purification" McGraw-Hill Book Company, Incorporated., 1960

Part 2 - CO_2 Removal by Non-Regenerative Processes

314 Introduction

CO_2 absorbents have been used in U.S. submarines for many years - as far back as World War I.(*1) However, until World War II, the material used was soda lime, and, until 1954, the use was for emergency air revitalization only. Present practice is to provide canisters of lithium hydroxide (LiOH) for emergency use in all submarines and to provide portable blower assemblies (manifold or canister receptacles) for use with canisters in submarines of the SS 563 Class and later submarines. All new procurements of LiOH are for the pelletized (granular) form in canisters suitable for use with canister receptacles and the same material is used by spreading (*2) for no power, emergency situations.

Because of LiOH's high cost, several other commercial absorbents (i.e., modern soda lime, baralyme) have been investigated as cheaper materials for submarine use. (*3,4,5,6) However, because of recent decreases in its cost and its unexcelled performance, LiOH remains the standard material. Raw material ($LiOH \cdot H_2O$) is now being obtained at no cost from the Atomic Energy Commision for use in manufacturing the pelletized form (*7) but production costs remain relatively high.

(*1) Refers to References at end of text

As in the case of chlorate candles, the LiOH system offers a quick solution to any sudden requirements by battery powered submarines. No installation (other than possibly for stowage) is required and the system is simple and reliable.

315 Technical Description

The reaction involved in the abosrption of CO_2 by LiOH is as follows:

$$2\ LiOH + CO_2 \xrightarrow{H_2O} Li_2CO_3 + H_2O + \triangle$$

where: LiOH = lithium hydroxide

CO_2 = carbon dioxide

Li_2CO_3 = lithium carbonate

H_2O = water

$\triangle$ = heat (approximately 1275BTU/lb LiOH)

Water is shown with the reaction symbol ($\longrightarrow$) because at least trace quantities of water appear to be necessary in the LiOH for the reaction to proceed at a useful rate - probably because CO_2 reacts in the form of carbonic acid (H_2CO_3).

Two physical forms of LiOH have been used in U.S. submarines - crystalline and pelletized (or granular). The latter was developed at NRL to permit use in beds through which air is passed but the two forms are equivalent for static (spread) use. Although crystalline material is still in use and in the supply system, expended material is being replaced with the pelletized form in canisters. Aside from having different stock

numbers, the two forms are readily differentiated by the method of packaging. Crystalline material is packaged in rectangular stainless steel cans holding approximately 15 lbs of LiOH while pelletized material is in double-ended cylindrical canisters holding approximately 6.3 lbs. (A limited amount of pelletized LiOH was packaged in long, cylindrical cans holding approximately 7.2 lbs. These cannot be used as canisters and have been removed from the supply system.)

For emergency use under conditions of no power, LiOH is spread on flat surfaces as described in the Bureau of Ships Manual (Chapter 38). For routine use or whenever a manifold assembly and power are available, pelletized material is used in canisters - a procedure which is more pleasant and efficient. Figure 3-5 can be used to calculate the operating cycle required to maintain an atmospheric CO_2 concentration of 1% when the numbers of personnel and manifolds are known. A CO_2 production rate of 0.1 lbs/man hour should be used for normal operations although, if all hands are quiet, 0.09 lb/man hour is probably adequate. As an example of this figure's use, assume 100 men and 3 manifolds:

$$\text{Total } CO_2 \text{ production} = 100 \times 0.1 = 10 \text{ lbs/hr}$$

$$CO_2 \text{ removal per manifold} = \frac{100}{3} = 3.3 \text{ lbs/hr}$$

From Figure 3-5, each manifold will remove an average of 3.3 lbs CO_2/hr for approximately eight (8) hours. Therefore, for the assumed conditions, a 1% CO_2 concentration can be maintained

in the submarine by changing canisters on all three manifolds every eight (8) hours. It can be seen that, although two (2) manifolds should be adequate, the cycle is much shorter (2 hours) and the LiOH utilization efficiency is much lower.

Although LiOH can be used to absorb chlorine (Cl_2) (*2), its effectiveness at hygienic concentrations (0.5 - 5.0 ppm) is uncertain (*9). Naval Research Laboratory has studied the use of granular LiOH and lithium hydroxide monohydrate ($LiOH \cdot H_2O$) (*10) to absorb high concentrations (0.4 - 1.5%) of Cl_2 from battery exhausts and found $LiOH \cdot H_2O$ to be considerably better than LiOH. For example, at 0.42% Cl_2, $LiOH \cdot H_2O$ absorbed 26% of theoretical under the test conditions while LiOH absorbed only 4.5%. Tentative conclusions from presently available information are:

1. LiOH is of uncertain value for removing Cl_2 from atmospheres at concentrations not immediately lethal to personnel.

2. Performance is improved by moistening LiOH to form $LiOH \cdot H_2O$ (approximately 43% water by weight)

Naval Research Laboratory is investigating performance of LiOH at low Cl_2 concentrations (*11) and results will be disseminated when available.

316 Operating Experience

Pelletized LiOH was evaluated for submarine use in tests in 1945 aboard USS SAILFISH. A hopper system involving use of

bulk LiOH was evaluated in 1953 aboard USS TROUT (SS566) but proved to be so inconvenient that efforts were turned toward developing a canister system. An early form of this system was evaluated in 1958 in USS SEAWOLF (SS(N)575) and results provided the basis for the present system. No subsequent operational experience is known to the Bureau, but there is little doubt of the system's effectiveness and reliability.

317 Stock Numbers

Manifolds are Bureau furnished equipment and are described as follows:

Receptacle, CO_2 Absorbent Canister FSN S4460-767-5065

Lithium hydroxide is stocked by Submarine and Reactor Parts Supply Office as follows:

Lithium Hydroxide (6.3 lb canister) FSN P6810-559-3261

Lithium Hydroxide (12-15 lb can) FSN P6810-558-2561

The 6.3 lb canisters contain pelletized material and are the only form that can be used in manifolds. The 12-15 lb cans contain the old, crystalline material which is gradually being replaced with the pelletized form.

REFERENCES AND BIBLIOGRAPHY

1. Submarine Ventilation, BUMED Bulletin No. 4 dated 15 March 1919

2. Bureau of Ships Manual, Chapter 38

3. McConnaughey, W.E., Crofford, W.N., Thomas, F.S., and Andreatch, A.J., "Atmospheric Control on Two Extended Dives on the USS TROUT (SS566)", NRL Report 4430 dated October 1954

4. McConnaughey, W.E., "Carbon Dioxide Absorption: A Study of Baralyme and Soda-Lime in the Lithium Hydroxide Hopper", NRL Memo Report No. 88 dated November 1952

5. Bureau of Ships Report on Travel (CONFIDENTIAL), Ser 649B-045 of 1 December 1958

6. Smith, S.H., Jr., "A dry Chemical System for Carbon Dioxide Removal from Submarines", NRL Report 5563 dated November 1960

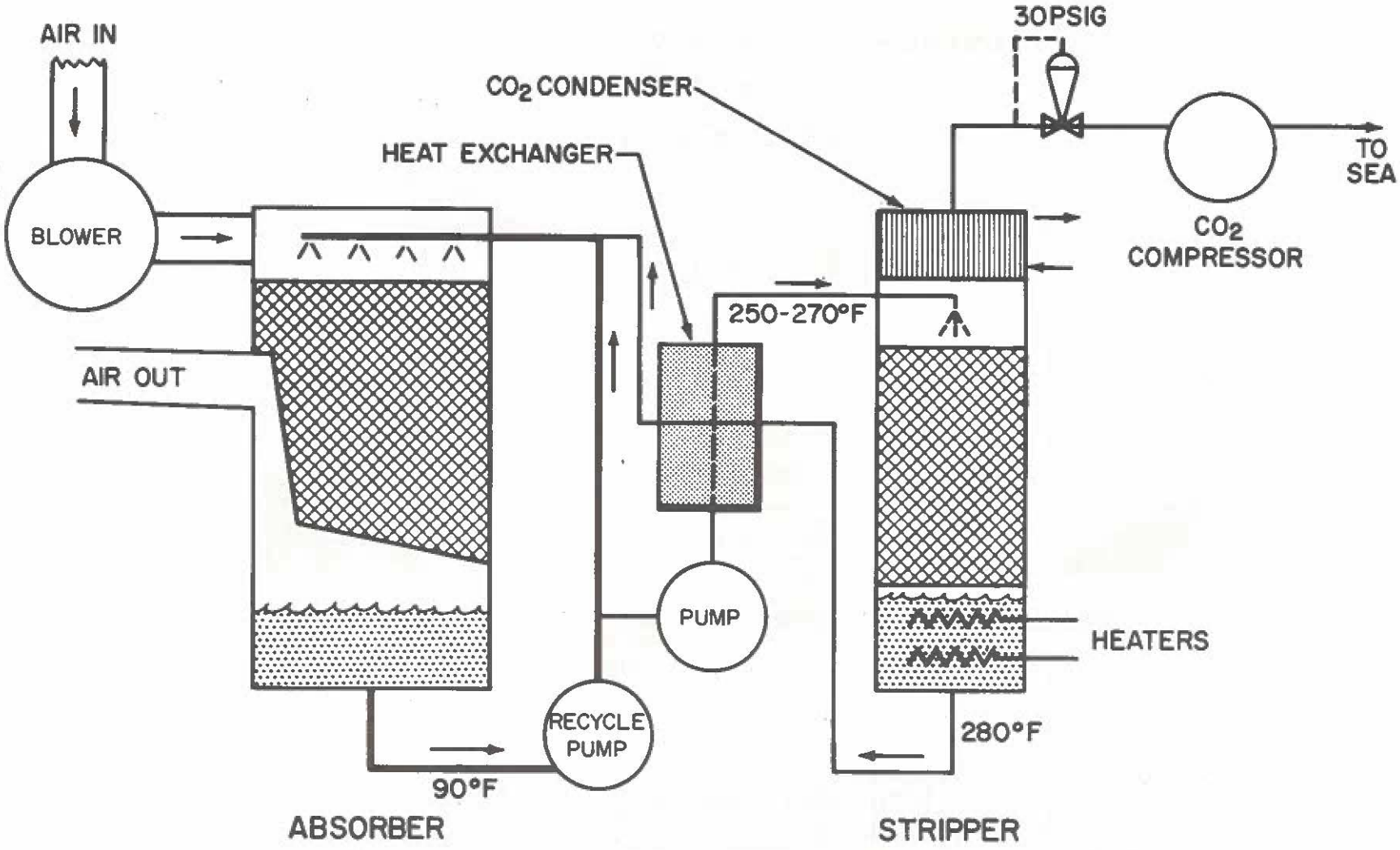
7. "Military Specification - Lithium Hydroxide (LiOH), Technical" MIL-L-20213D (SHIPS) dated 11 December 1959

8. Miller, R.R., et al, "Experimental Control of CO_2 and Oxygen Concentrations Aboard the USS SEALFISH", NRL Report P-2665 dated October 1945

9. Naval Research Laboratory ltr 6130-56:RRM:be, Naval Research Laboratory Problem C08-05 (advance copy)

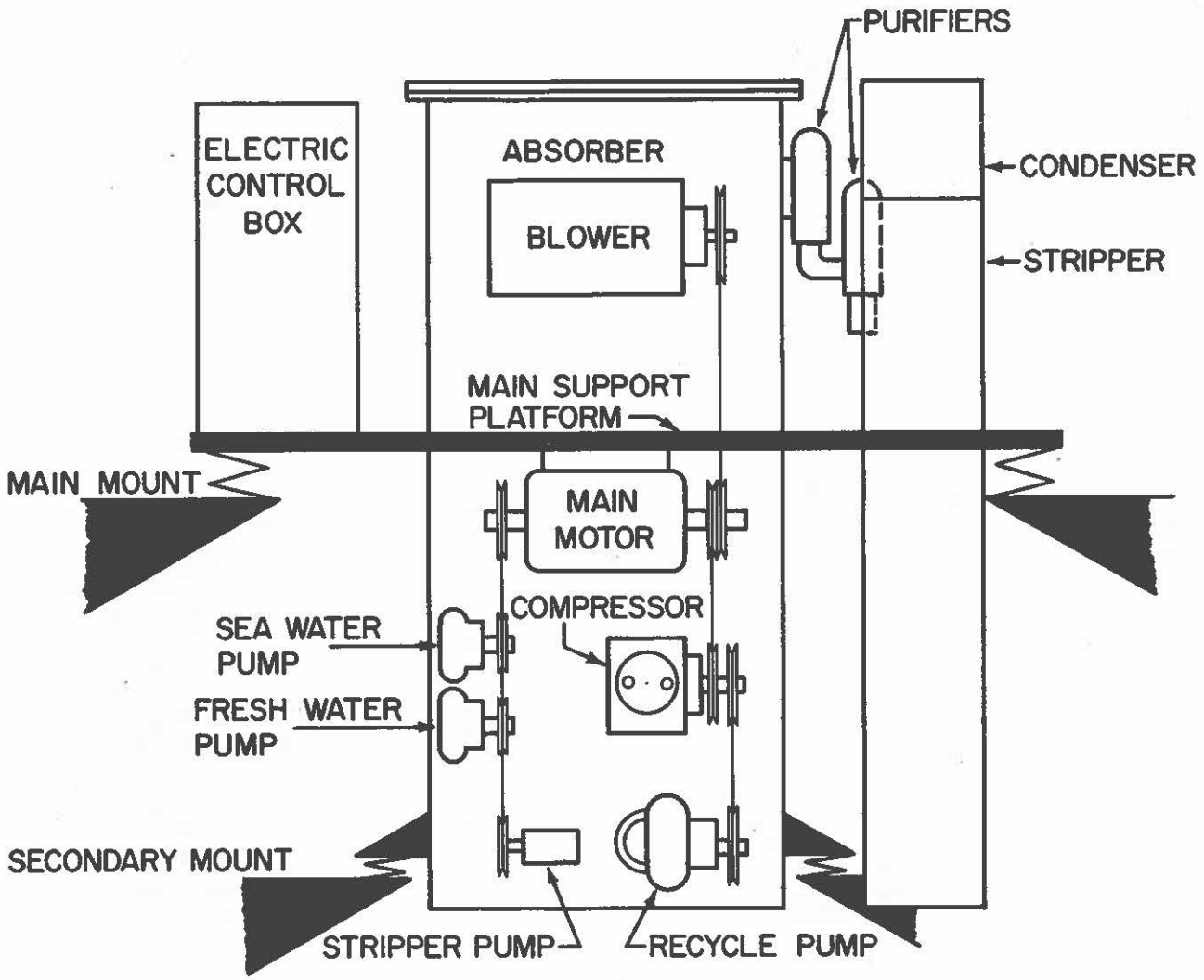
10. Naval Research Laboratory Report P 1586 of 17 July 1940

11. Telecon Mr. R.R. Miller (NRL-6130) and Mr. W.E. McConnaughey (BUSHIPS/649) on 15 March 1961



CO_2 SCRUBBER
SIMPLIFIED FLOW DIAGRAM

FIGURE 3-1

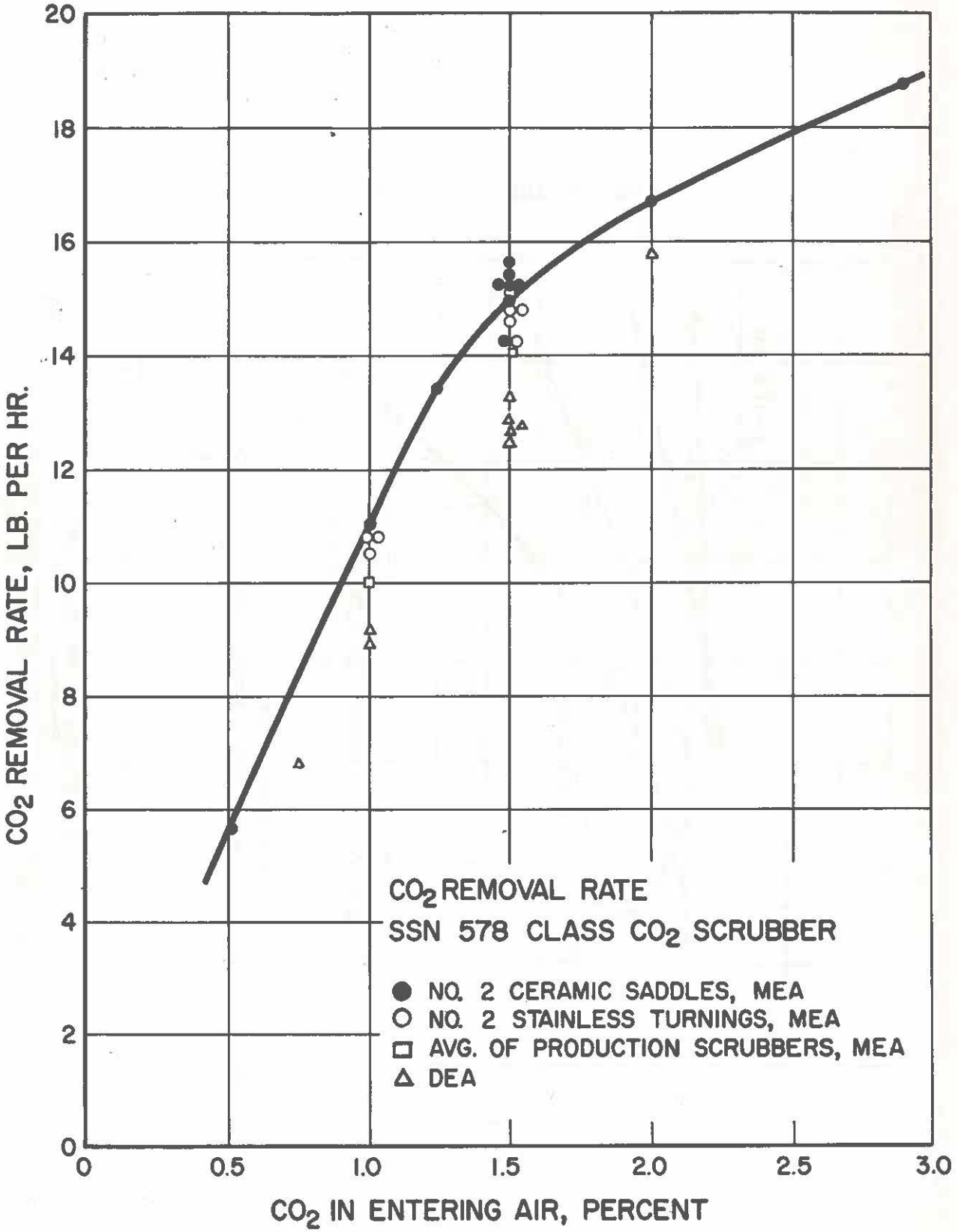


CO_2 SCRUBBER

FRONT VIEW

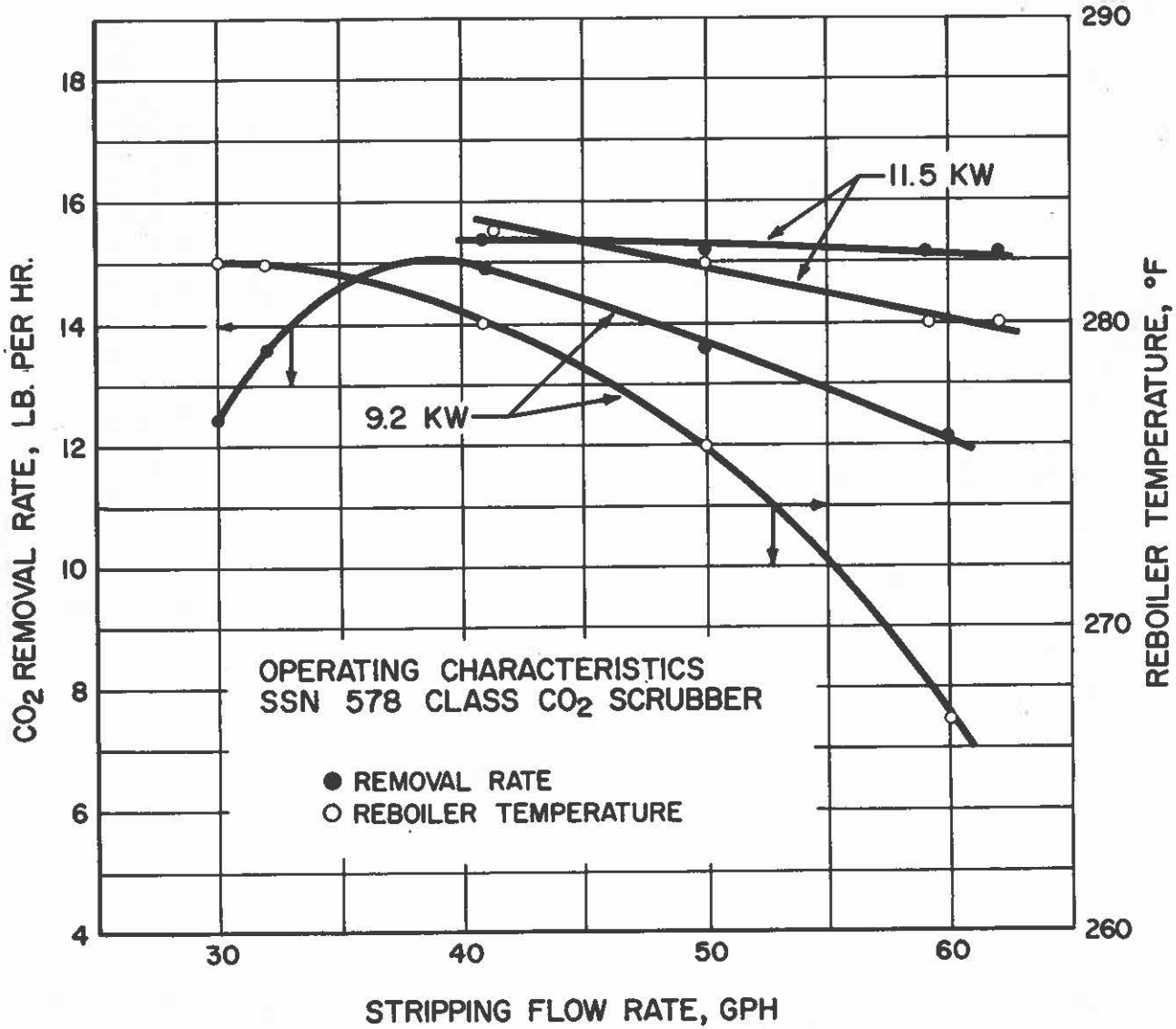
LOCATION OF MAJOR COMPONENTS

FIGURE 3-2



This chart, adapted from reference 3-R-5, is based on a Mare Island Type CO2 scrubber using approximately 4.7 normality MEA and processing 171 cubic feet per minute of air.

FIGURE 3-3



This chart, adapted from reference 3-R-5 is based on a Mare Island type CO2 scrubber using approximately 4.7 normality MEA and processing 171 cubic feet per minute of air containing 1.5 percent CO2.

FIGURE 3-4

LiOH MANIFOLD ABSORPTION RATE AT 1.0% CO_2

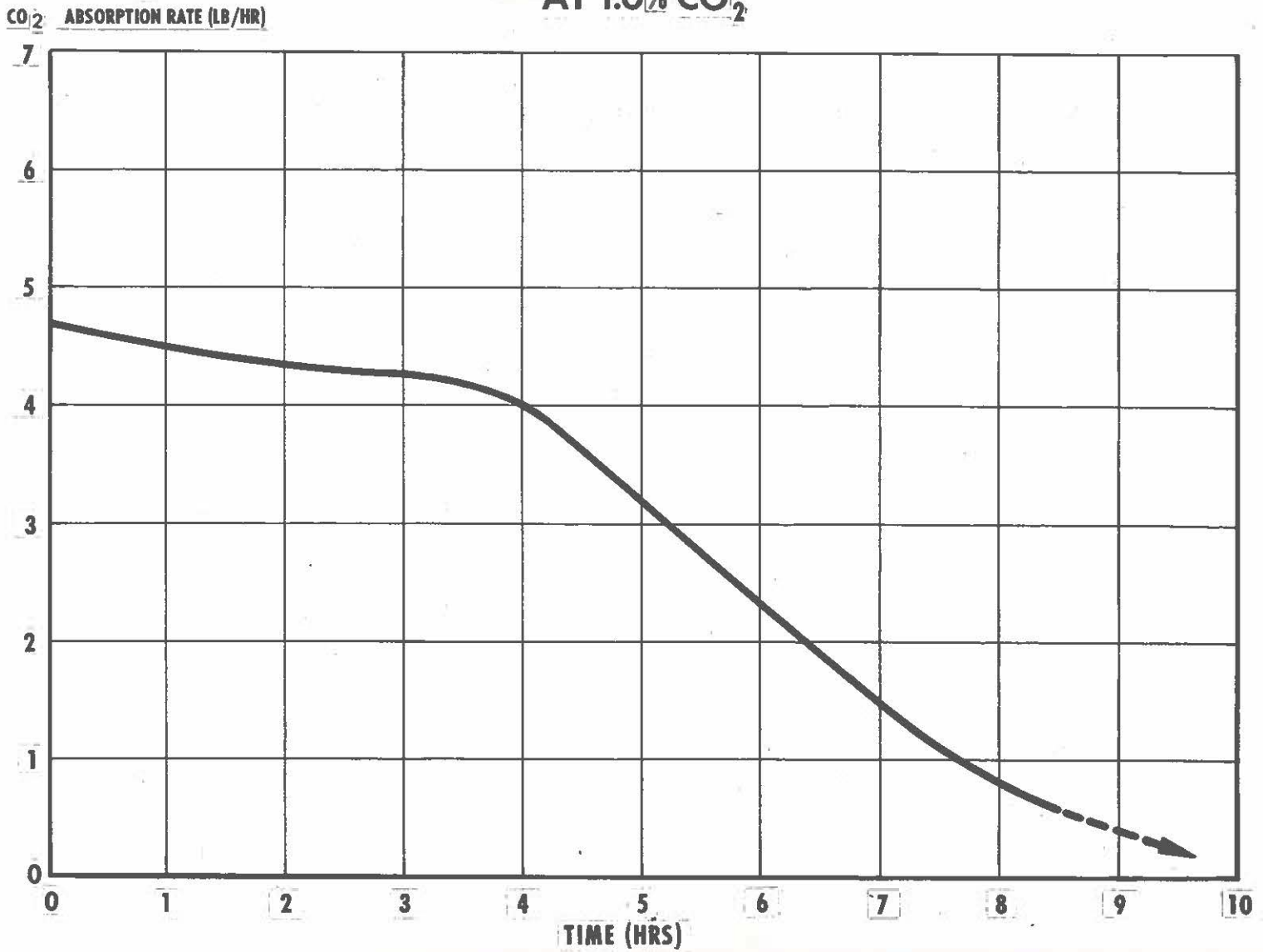


FIGURE 3-5

SECTION 4

$CO-H_2$ BURNER

4-R-0 - References

4-1B-1 - NAVSHIPS 338-0351, Technical Manual, CO and H_2 Burner Mark II, Size 250 CFM, Desomatic Products, Incorporated

4-TM-1 - Chapter 62 of Bureau of Ships Technical Manual

401. Introduction

The purpose of the $CO-H_2$ burner is to remove carbon monoxide, hydrogen and hydrocarbons. The carbon monoxide is produced from the cigarette smoking of the personnel, cooking (particularly when foods are burned), the over-heating of electrical equipment and a small amount from the human body. The amount of carbon monoxide that a person can withstand depends on the amount of time that he is subjected to it. On nuclear submarines (which submerge for long periods), the CO level must be low. A maximum limit of 25 PPM was the basis that the $CO-H_2$ burner was designed to maintain. The hydrogen's major source of production is from the charging of the batteries, but it is also produced from the oxygen generator, possible leakage of the hydrogen bottles and the sanitary tank vent. Submarines have reported that maintaining a concentration of 1.2 percent or less is not considered a problem. A maximum safe concentration of 3 percent is stated in paragraph 62-701 of reference 4-TM-1. The numerous types of hydrocarbons are produced from such sources as the diesel fuel oil tank vent, cleaning solvents, lube oils, fats and cigarette lighter fluid.

402. Process

Disposing of the carbon monoxide, hydrogen and hydrocarbons at a reasonable temperature can only be accomplished with the aid of a catalyst. The surface of a catalyst acts as a substance which changes the speed of the chemical reaction but remains in its original concentration at the end of the reaction. The catalystic chemical reaction converts carbon monoxide to carbon dioxide, hydrogen to water vapor and hydrocarbons to carbon dioxide and water vapor.

403. Catalyst

The catalyst which is most efficient, has a long life and does not adsorb hydrocarbons at the burner operating temperature, contains copper oxide and manganese dioxide. It is a product of the Mine Safety Appliances Company that is named hopcalite and carried under FSN PM6850-605-7854 by the Submarine and Reactor Parts Supply Office. An aluminum oxide catalyst which is produced by the same manufacturer for the burning of hydrogen only has a low efficiency in the burning of carbon monoxide and will adsorb hydrocarbons after only a short period of use. For the above reasons the aluminum oxide catalyst, which is carried under FSN P6850-547-0673, should never be used in the CO-H_2 burner. In case the stock numbers are incorrect, a visual inspection can easily detect one from the other. The hopcalite is charcoal black with a very slight reddish tint while the aluminum oxide is grayish in color with a brown tint.

404 Submarines have reported that the life of the hopcalite catalyst is not known. If the catalyst charge is allowed to rest, it will recover and be as active as a new catalyst. On submarines where the carbon monoxide level can be maintained with the operation of one CO-H_2 burner (alternating the operation of the two units every ninety to one hundred hours) the catalyst will automatically recover. On submarines where both burners have to be kept in operation to maintain the desired carbon monoxide level, the catalyst may lose its efficiency before a mission is completed. If the desired carbon monoxide level cannot be maintained and replacement of the catalyst is required, the used catalyst should not be disposed of. The used catalyst should be stored in an open container to allow it to recover for future use.

405 The efficiency of the catalyst should conform with Table 2-1-3 of reference 4-1B-1 for the burning of carbon monoside and hydrocarbons and with Table 2-1-2 of reference 4-1B-1 for the burning of hydrogen. However, if input and output readings indicate that the efficiency of the catalyst is much lower than what is shown in the tables of reference 4-1B-1, the catalyst bed should be checked for a possible by-pass. This can easily be done by taking a catalyst bed pressure drop reading. A by-pass would make the catalyst bed reading much lower than what is shown on Figure 4-1. A by-pass in the catalyst bed will occur from settlement of the catalyst and can be corrected by adding more catalyst.

406 By-passing of the catalyst bed not only lowers the burning efficiency of the catalyst, but the hydrocarbons which are present may produce a toxic gas. For example, if methyl alcohol (which burns 100 percent with the aid of the catalyst) is allowed to by-pass the catalyst bed, it will produce formaldehyde which affects the eyes of the personnel. The cartoon, Figure 4-2, is an example of the condition of the personnel on the NAUTILUS when she arrived at Panama. The by-passing of the heated hydrocarbons does not permit complete combustion and their partial oxidation produces a by-product which may be a toxic gas. The type of by-product produced depends on the class of the hydrocarbons that are partially oxidized.

407 Airflow

The airflow for the Mark II CO-H_2 burner should be 250 CFM with normal airflow restrictions. Figure 4-1 and Figure 3-1-1 of reference 4-1B-1 give pitot tube readings for various airflows, indicating that a reading of 2.55 corresponds to an airflow of 25 CFM. An increase in airflow restriction in the filter, heat exchanger matrix or catalyst bed will naturally decrease the airflow. If there is a decrease in airflow, the source can be determined by taking pressure drop readings of the filter, the heat exchanger and the catalyst bed and comparing them with the curves shown on Figure 4-1 (which are typical curves which may change with higher or lower pressure drop values for difference CO-H_2 burners).

The summation of pressure drops can also be obtained from Figure 4-1 for any airflow. For example, the pressure differentials at 250 CFM are 2.2 for the filter, 3.2 for one side of the heat exchanger (this is doubled to 6.4 to include the outlet side) and 4.5 for the catalyst bed. By adding these values (2.2 + 6.4 + 4.5) we obtain a total pressure drop of 13.1.

When the airflow is decreased because of an increase in restriction, the sum of the pressure differentials at the decreased airflow are equal to the sum of the pressure differentials at 250 CFM. For example, let's assume that restriction has decreased the airflow from 250 to 150 CFM as determined by the pitot readings. Figure 4-1 indicates that an airflow of 150 CFM should give pressure differential of 0.8 for the filter, 1.15 for the heat exchanger, and 1.6 for the catalyst bed. By adding 0.8 + 2 x 1.15 + 1.6 we have a total pressure drop of 4.7. Assuming a clean filter and a clear catalyst bed the readings should approximate 0.8 for filter and 1.6 for catalyst bed for a total of 2.4. This subtracted from 13.1 would give 10.7 for loss across both sides of heat exchanger or $\frac{10.7}{2}$ = 5.35 which should be the reading for the heat exchanger indicating from the excessive pressure drop that the restriction is in the heat exchanger.

If the pressure drop readings do not conform with Figure 4-1, the curves can be

corrected with the equation:

$$\Delta P_2 = \left(\frac{V_2}{V_1} \right)^2 \Delta P_1$$

Where:

V_1 = Original Airflow (CFM)

V_2 = Decreased Airflow (CFM

ΔP_1 = Original Pressure Drops

ΔP_2 = Pressure Drops for V_2

408 Temperatures

In order to obtain complete combustion of the hydrocarbons, the catalyst has to be kept at a temperature of approximately 600°F. Carbon monoxide and hydrogen will burn at a much lower temperature so the only reason for heating the catalyst to 600°F is to enable it to burn the hydrocarbons. To heat a quantity of 250 (CFM) of air from an inlet temperature of 80°F to 600°F would require a heat load of approximately 45 KW. The temperature of the discharge air from the burner would then be 600°F which is not permissible. To lower the 600°F air to an acceptable temperature would require an air conditioner of approximately 11.5 Tons. This brings the importance of the heat exchanger into the picture. The rotating matrix heat exchanger has a heat

efficiency of about 80 percent, which reduces the heat load of 45 KW to 9 KW and eliminates the need of a 11.5 Ton air conditioner. The heat exchanger has to be a surface to air type which means that its efficiency is related to the amount of its surface area. This means that to obtain a large surface area without using a large size unit, that the ratio of the surface area to the volume of the element would have to be high. If we look at the equations for the surface area and volume of a cylinder: π DL = Surface, $\pi D^2L/4$ = Volume, where D is the only variable, we can see that the greater the value of D the lower the ratio. Therefore, the ideal way to obtain the highest ratio would be to use a very large number of cylinders that have very small diameters. But to provide the cylindrical element with sufficient strength, we have to compromise with a minimum diameter. It is also important to space the cylindrical elements far enough apart to allow the air to pass across them without too much loss in static pressure. The heat exchanger matrix (which consists of many layers of stainless steel screen wire) complies with the requirements of a large surface area, a small volume, strength and air passage at a reasonable pressure loss. Looking at Figure 2-1-1 of Reference 4-1B-1, we can outline the process of heating 250 CFM of air from 80°F to 600°F with a heater load of only 9 KW. More than 80 percent of the heat produced by the 9 KW heater is picked up and held on the matrix surface

on the discharge side. With the matrix rotating, the collected heat is carried over to the inlet side where it is released to the incoming air, thus increasing the temperature of the incoming air. As the temperature of the incoming air leaving the matrix is increased, the temperature of the discharge air entering the matrix is increased and more heat is then carried over to the incoming side. After approximately two hours, the temperature of the air entering the catalyst will be 600°F. This means that when the 80°F incoming air passes through the matrix that the heat which is transferred from the discharge side to the inlet side raises its temperature to approximately 500°F. The heaters then heat the air to 600°F before it passes through the catalyst bed. After passing through the catalyst bed the 600°F air passes through the matrix where the heat is picked up and the temperature of the air is lowered to approximately 130°F. When the air temperature at the catalyst bed reaches 600°F, the heaters will automatically cut off but because of the mass of the catalyst bed and the matrix, the temperature cannot be maintained right at 600°F. The air temperature will continue to rise until it reaches about 625°F at which the amount of heat transferred begins to decrease since the heaters are cooling down. When the temperature drops to 600°F, the heaters come back on but the temperature will continue to drop to about 585°F. This forms a cycle of heaters on and heaters off

because the size of the heaters to heat the air and masses (with the aid of the heat exchanger) is slightly more than is required.

409 Hydrogen Burning Temperatures

When carbon monoxide, hydrogen and hydrocarbons are burned they contribute additional heat, but the concentrations of carbon monoxide and hydrocarbons are so low that the amount of heat which they provide can be neglected. However, at times the concentration of hydrogen may be high enough to produce an excessive amount of heat. One percent of hydrogen will increase the temperature of the air 180°F. When we consider that the heaters which are controlled to maintain the air temperature at approximately 600°F, increase the temperature of the air only 100°F (500° - 600°F) it is quite obvious that the temperatures will increase when the uncontrolled burning of one percent hydrogen takes place. To begin with if the temperature of the air entering the catalyst bed was 600°F, the temperature on the discharge side of the catalyst bed would increase from 600°F to 780°F, which allows the matrix to recover more heat and increase the temperature of the incoming air. If this were to continue, the temperatures would build up until the increased heat came in equilibrium with the heat loses from the burner to the space. However, this is prevented by opening the valve on the bleed-off coil to reduce the quantity of air passing through the discharge side of the

matrix so the heat recovery at the increased temperature will be the same as the full flow at 600°F. The amount of air to be bled is determined by maintaining a 600°F temperature in the air just before it enters the catalyst bed. This temperature is shown on the indicator. The easiest way to keep the temperature at 600°F is to open the valve slightly more than is necessary. This allows the heaters to cycle on and off to provide the additional heat and control the temperature.

410. Heat Exchanger Maintenance

Maintenance problems of the heat exchanger refer to two things; (1) clogging of the matrix which restricts the airflow and (2) deterioration of the stainless steel screen in the matrix. Both of these troubles are caused by the presence of aerosols, moisture and F-12.

a. Without the presence of moisture or F-12, the aerosols will not clog the matrix. With the matrix in a dry condition, the aerosols that are collected on the inlet side will be blown out when the matrix rotates to the outlet side. However, if moisture enters the burner in either a liquid or vapor form, it will allow the aerosols to stick to the matrix screen. As the collection of aerosols builds up, the airflow is restricted and the increased air velocity on the inlet side, forces the aerosols deeper into the matrix. It is also possible to clog the heat exchanger matrix when moisture is present due to the collection of pulverized catalyst (particularly when the bed is refilled) on the discharge side. Because of the high temperature of the bottom of the matrix, moisture would be present only in the top section, thus allowing the pulverized particles to pass through most of the matrix before being collected.

b. The presence of F-12 in the ambient air will clog and deteriorate the matrix if either moisture or aerosols have collected on the surface of the matrix. What takes place is that when F-12 is heated to a temperature of 600°F a small percentage of it decomposes to a fluoride vapor. When the fluoride vapor passes through the discharge side of the heat exchanger, if any moisture or aerosols are present on the matrix surface, they will absorb the vapor and convert it to hydrofluoric acid which corrodes the matrix. Once the corrosion starts, the clogging of the matrix accelerates. The corroded surfaces act as an absorbent for additional fluoride vapors and help collect more aerosols. It should be noted that the amount of moisture which is required on the surface of the matrix for the absorption of fluoride vapor is quite low. When the moisture content of the surface of the matrix on the discharge side is in equalibrium with air that has a relative humidity of 35%, it will start absorbing the fluoride. When the hydrofluoric acid corrosion of the matrix takes place, it will dispose of parts of the top layers of the matrix screen. This is considered the normal way it would attack the matrix screen for two reasons; (1) the top layers have the lowest temperature which would permit them to have the highest moisture content on their surfaces plus their ability to collect more aerosols, and

(2) after the corrosion has penetrated completely through the wire of the screen and it breaks into small parts the incoming air would force some deeper into the matrix and the outgoing air would blow others into the discharge duct.

c. To delay the clogging and corrosion of the heat exchanger matrix the following action has been taken:

(1) To decrease the size and quantity of aerosols that coming in contact with the matrix screen, the burner has been provided with a fiber filter on the inlet side of the fan. This particular filter material was selected on the basis that it would collect a large percentage of the aerosols with an acceptable restriction to the airflow. The filter material, FSN PM4240-650-0761, comes in rolls of 50 lineal feet 23 inches in width, which has to be cut and applied as described in paragraph 5-1-2 of reference 4-1B-1.

(2) The catalyst bed is evenly mixed with 10 percent of lithium hydroxide by volume although reference 4-1B-1 states that the mixture is hopcalite and marble chips. The lithium hydroxide or marble chips will absorb about 90 percent of the fluoride that is produced from the decomposition of F-12. There is no difference in the performance of lithium hydroxide and marble chips in the absorption of fluoride vapor but the marble chips cost considerably less and have no effect on the personnel when they are handled. If this is the case, then the question is "why don't we use marble chips instead of lithium hydroxide"? The answer to this is that they have not become available as a stock item. The only reason the marble chips are not in stock is because a simple means of testing their

performance has not been determined. When this has been accomplished, the specification for the hopcalite catalyst will be ammended to include a 10 percent mixture of marble chips which meet the performance test requirements. Some of the submarines have a lithium hydroxide bed in the dischage duct from the burners. This is considered to be of little importance since most of the small amount of fluoride vapor that is not picked up by the lithium hydroxide in the catalyst bed is collected on the wet surface of the after cooling coil and drained off. Although the cooling coil is monel, the hydrofluoric acid will cause some corrosion and require cleaning after a reasonable period of time. To prevent the condensation of the cooling coil from dumping back into the burner it is of utmost importance to see that the drain line from the after cooling coil does not become clogged from the hydrofluoric acid corrosion.

d. The major maintenance problem of the CO-H_2 burner is the heat exchanger. When clogging of the matrix takes place, it should be removed and cleaned. The amount of cleaning that can be done depends on the degree of clogging that has been allowed to take place. If the cleaning is done when the cloggingis at an early stage, it can be restored to a satisfactory condition. The best way to determine when the matrix should be cleaned is to see if there is a reasonable increase in the pressure drop reading across it (Figure 4-1 and paragraph 407). The cleaning of the matrix can be accomplished as stated in paragraph 5-2-3 of reference 4-1B-1 or by the ultrasonic method that has been used by some submarine. However,

if the matrix has gone beyond the state of cleaning, a new one may be obtained from the Submarine and Reactor Parts Supply Office. The units are being procured at this time and have not been assigned a stock number so they will have to be identified by the manufacturer's part number shown on page 7-3-7 of reference 4-1B-1. In addition to the instructions given in paragraph 5-2-3 of reference 4-1B-1 for the disassembly and reassembly of parts to obtain access to the matrix, precaution should be taken to ensure that the small tubing for the pressure drop and pitot readings is not damaged and is reassembled with non-leaking conditions. Because of the small size of the tubing a slight leak would give a false reading on the pressure gage.

411. There have been reports that the efficiency of the burner for the removal of carbon monoxide does not conform with the 100 percent as indicated on Table 2-1-3 of reference 4-1B-1. There are several ways this could occur with the burner, namely, (1) the catalyst bed is not completely filled so that a small opening will allow most of the air to by-pass the catalyst because of the large differences in airflow restriction, (2) continuous use of the same catalyst charge for a long period has caused a change to occur on its surfaces, thus reducing its efficiency (the change could become great enough for the efficiency of the catalyst to approach zero), and (3) the wrong catalyst was used. As pointed out in paragraph 403, the aluminum oxide catalyst which is used for the burning of hydrogen only has a short life and low efficiency in the burning of carbon monoxide.

412. The Mark III CO-H_2 Burner

Another CO-H_2 burner that has double the capacity of the Mark II was developed and is now in production for the larger nuclear submarines which require such capacity. The only difference in the design of the Mark III is that it delivers 500 CFM in lieu of 250 CFM. Of course, the size of the major components are increased on the same scale. However, the development and production of the Mark III design got underway too late to be delivered for installation in any of the nuclear submarines prior to the SS(N)612. Present plans are that all submarines after the SSB(N)611 will receive 500 CFM burners.

413. A Possible Future Design

Because of the clogging and deterioration of the heat exchanger matrix on the Mark II design which will also take place on the Mark III, and the trouble to obtain accessibility to the matrix, a study of a completely different design has been made. The change that has the major importance and which the study has been based on is a different type of heat exchanger. The new type of heat exchanger consists of two stationary monel finned units which are a liquid to air type, coupled together with a canned pump that would prevent any possible leakage of the liquid. The air would enter one of the stationary units and discharge from the other. Such a design would have many benefits: (1) the aerosols in the

incoming air would collect on the inlet section only and not be present on the discharge section to act as an absorbent for the fluoride vapor, (2) if enough aerosols ever collected on the inlet side to require cleaning, accessibility to the unit would be easy so it could be cleaned in place with hot water or compressed air, (3) the life of the finned monel tubes that are subjected to the fluoride vapor would be much longer than the present matrix, (4) the pressure drop through the heat exchanger would be low, resulting in a smaller fan, and (5) the burning of hydrogen would be controlled automatically by controlling the rate of circulation for the liquid to enable it to pick up more heat which would then be removed with a small liquid to liquid heat exchanger before the liquid is transferred over to the inlet air side.

MARK II CO-H_2 BURNER

MAGNEHELIC PRESSURE GAGE READINGS

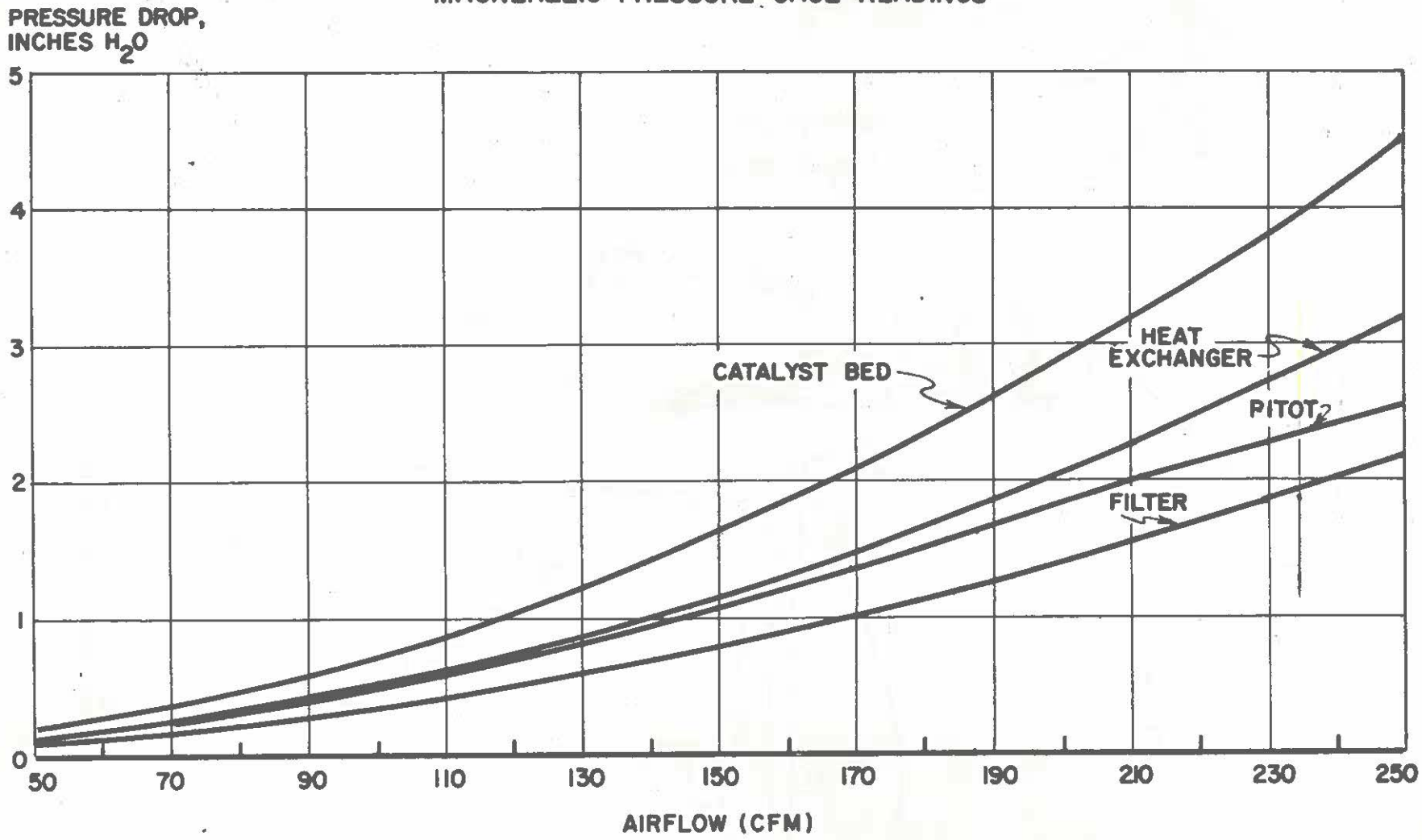
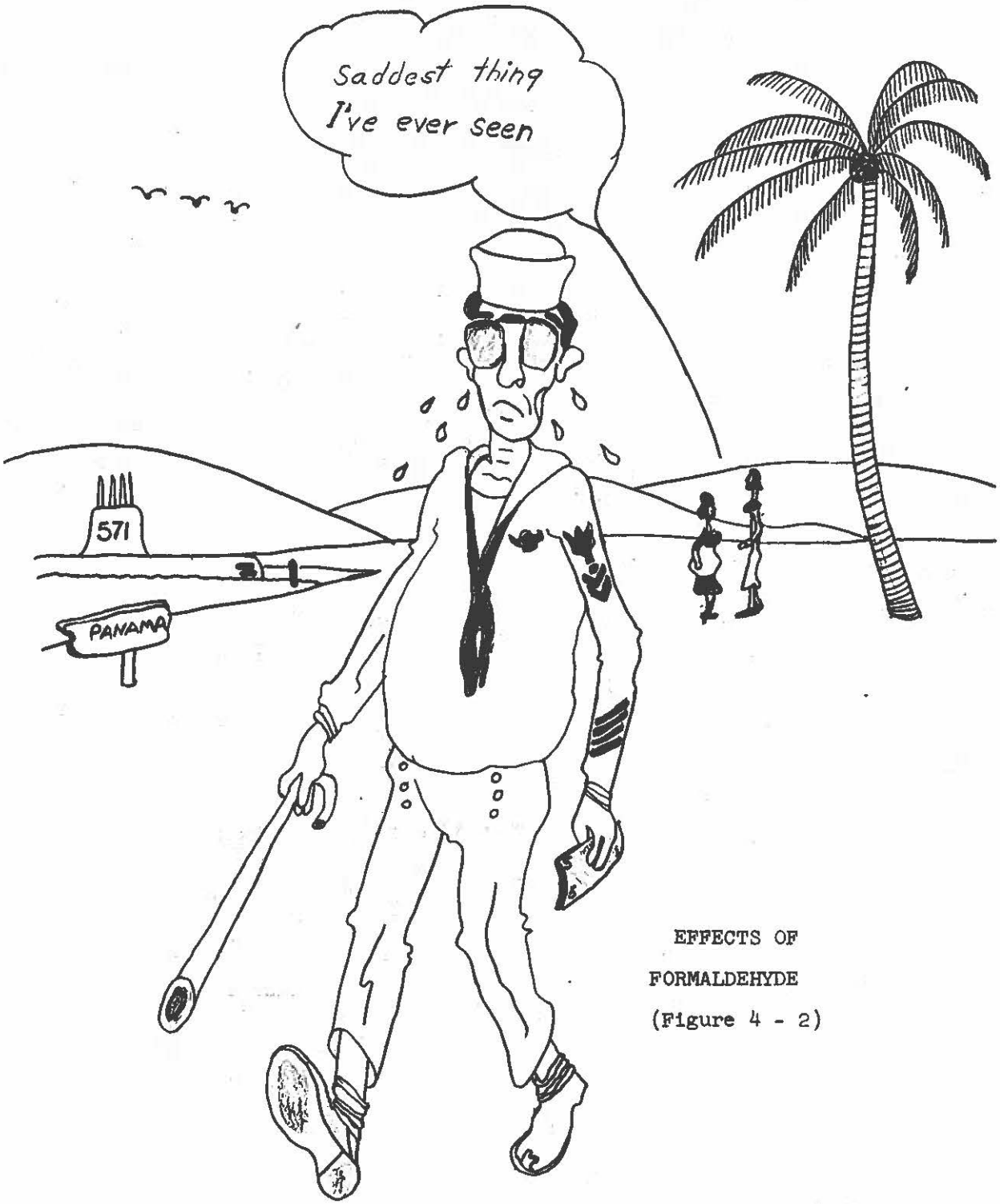


FIGURE 4-1



EFFECTS OF
FORMALDEHYDE
(Figure 4 - 2)

This cartoon was drawn by a NAUTILUS crew member who experienced the effects of formaldehyde as the submarine came into Panama.

Section 5 - AEROSOL REMOVAL

501 Purpose

The purpose of this section is to describe the need for and to outline the various procedures used for aerosol removal. Particular emphasis will be placed on the electrostatic precipitator as it is considered the best aerosol removal equipment for submarine application. The subsequent test will develop the Bureau's approach to this problem.

502 Introduction

The advent of the nuclear submarine has created new and unusual atmosphere control problems and has added new importance to old existing problems. In the latter category is that of aerosol removal. Ventilation systems for years have been equipped with mechanical (impingement) filters, usually located at the inlet to the system. The primary function of these filters was to remove the large dirt particles from the airstream to prevent their collecting on fans, cooling coils, and the duct system itself, and thus reducing the system performance. With the sealed atmosphere of the nuclear submarine, old methods were inadequate to protect equipment and the additional problem of personnel protection was introduced.

503 Aerosols

1. Definition - Aerosol may be defined, for our purpose, as particulate (solid or liquid) matter suspended in the atmosphere.

2. Problem - As indicated in paragraph 502, the aerosol problem was considered for years as one of equipment protection. In the case of the conventional submarine the availability of copious quantities of fresh air obviated the personnel problem and also precluded efforts to determine the aerosol's characteristics.

As long submergences (10-20 days) became routine for nuclear submarines, the aerosol problem,both equipment and personnel, became increasingly evident. Early tests conducted in USS SKATE (SS(N)578) indicated aerosol concentrations of 0.4 - 0.5 milligrams/cubic meter which compares to that encountered in a heavy industrial area. Analysis of the aerosol indicated that, while the concentration was not an extremely serious problem, the constituents of the aerosol were from the personnel protection aspect. Also this heavy aerosol concentration and the small particle size amplified the older consideration of equipment protection. Continued fan failures were traced to heavy aerosol deposits on the fan blades and housing. Aerosols are also suspected of reducing cooling coil efficiency and increasing electronic failures by collecting on surfaces exposed to airflow.

3. Aerosol Size and Composition - The Naval Research Laboratory collected air samples from various nuclear submarines for laboratory analysis. This analysis indicated that 50 - 75%

of the aerosol was cigarette smoke with the remainder derived from cooking, lubricating oil, etc. The median particle size was determined to be less than one (1) micron in diameter, due primarily to the high cigarette smoke content. Recent hydraulic system casualties, which introduce large quantities of oil into the space as a mist, may slightly alter the general composition but it is suspected that even the oil mist particle size will be small due to the pressures which create it.

4. Solution - The particle size and the possible effect on personnel led to the search for a filter of high efficiency for particles sizes of less than one (1) micron and capable of handling large air quantities (range of 20,000 - 25,000 CFM). The only practical filter satisfying these requirements was the electrostatic precipitator. Mechanical filters such as the Cambridge absolute filter could not be considered because of high pressure loss and/or extremely large volume.

504 Electrostatic Precipitators

1. The purpose of this section is to discuss in broad terms electrostatic precipitators as air cleaners with particular emphasis on those equipments which the Bureau is procuring for installation on all nuclear submarines.

2. Any discussion of electrostatic precipitators must start with a clear definition of the equipment. An electrostatic precipitator may be defined as an equipment which utilizes electric

forces to separate suspended particles (aerosols) from gases. In reference to the Navy's application of electrostatic precipitators, we may further define the equipment as a highly efficient filter device for particle sizes between 0.1 and 10 microns. The filtration of aerosols from a gas by electrostatic precipitation requires three fundamental steps:

a. Electrical charging of suspended particles (ionization).

b. Collection of the charged particles in an electric field. (Collection)

c. Removal of collected material from the collecting section. (Cleaning)

The fundamentals above are required in all electrostatic precipitators of any design or type. Two basic types of precipitators, each best suited to a particular application, are available today. These types, (1) the single stage precipitator and (2) the two stage precipitator, are best suited to industrial gas cleaning (gross contamination, fly ash), and air cleaning (low particle concentration and sub-micron particles) respectively. Very briefly, the two types of precipitators may be defined as follows:

a. Single stage - Continuous ionization with simultaneous collection, i.e., the ionizer or charging section and the collecting section are one and the same. A single electrical field is used for charging and collecting. See figure 5 - 1.

b. Two stage - Separate charging and collecting sections, each with its own electric field. Generally the ionizing voltage is about twice that of the collecting section. See Figure 5 - 2.

Both the single and two stage electrostatic precipitators may be constructed using either a tube type or plate type collecting section. A brief description is as follows:

a. Tube type - a nest of identical tubes with concentric high potential electrode suspended in center of each tube. It is generally used where small cross-sectional area but long run of duct is possible. Advantage of higher efficiency with disadvantage of higher pressure loss.

b. Plate type - Flat parallel plates having alternate hi-voltage and grounded plates. It has lower efficiency but short length.

3. Charging

Ionization is that process in which, by some external force, one or more electrons are removed from or added to the external shell of a gas molecule, to form gas ions. Charging of particulate matter results from capture of these ions.

In the case of electrostatic precipitators, the external force is the electric field created by the corona discharge surrounding the ionizer electrode, a bare, tungsten wire 5-10 mils in diameter suspended under slight tension. Either the positive or the negative ionization processes may be used, each of which had advantages and disadvantages in air cleaner application.

It is common commercial practice to use positive ionization for air cleaner applications. While this reduces efficiency to the 65-75% range, it eliminates any problem of ozone at voltages normally used commercially. The Bureau's approach is to maintain high efficiency and yet keep the ozone generation to a minimum. For this reason, negative ionization is utilized in Navy precipitators.

3.1 Negative Ionization

A high D.C. voltage is applied to the ionizer section so that the ionizer wire is negative with respect to the ground plates. This produces a non-uniform electrical field between the two elements which causes breakdown of the gas near the wire. The breakdown produces a visible glow ("corona") consisting of ionized gas which is the agency for charging the gas-borne particles. The ionizer current produces extremely high electron action within the wire and hence great numbers of electrons are emitted from the wire surface into the intense electric field of the corona discharge. These freed electrons move at very high velocity away from the wire and violently collide with gas molecules, freeing additional electrons from them. All the free electrons move away from the wire, continually colliding with gas molecules and freeing more electrons from them until the electron velocity is insufficient to free additional electrons from the molecule. The negative ions which result from the low velocity collisions continue to migrate away from the wire into a lower intensity field where they attach to dirt particles, imparting their electrical charge. The positive ions, molecules which have

lost an electron and are now positively charged, accelerate toward the ionizer wire. The resultant collisions with the wire free additional electrons so that the process is self-maintaining.

3.2 Positive Ionization

Positive ionization starts with an electron being freed from a gas molecule by the electrical field created by the positive ionizer wire. The resultant positive ion is repelled from, and the free electron attracted to, the ionizer wire. The free electron in moving toward the wire may have sufficient energy to free additional electrons when colliding with additional molecules. Such collisions result in additional positive ions. Any free electron is attracted to the ionizer and retained on it. The positive ions attach to dirt particles as explained in paragraph 5.3.1.

3.3 Ionizing Voltage

The ionizing voltage is the major factor affecting ionizer performance. Negative corona is more stable (i.e., has a higher arcing voltage) than positive corona and, therefore, is more desirable for high voltage, high efficiency Navy equipment. Although positive corona produces less ozone at low voltage, it loses this advantage at high voltages because of arcing.

4. Collection

Charged particles not collected in the ionizing section (approximately 80%) move from the ionizer into the collector section. Here the electric field supplies the external force to attract or repel the charged particle. Utilizing a negative collecting voltage, positive particles will be attracted to the charged plate and the negative particles repelled toward the grounded plates.

The mass of the particle and its velocity exert a force on the particles which tends to keep it moving in a straight path. The electric field created between the plates of the collector exert a force, acting perpendicular to the particle's motion, which tends to move the particle to the collector plates. Collection then may be considered as a problem in kinetics which are affected by the following factors:

(a) electric field strength

(b) air velocity

(c) particle mass and size

(d) length of collector cell

5. Power Supply

The electrostatic precipitator consumes very little power, approximately 0.2 kw per 1000 CFM of air. Therefore the power supply is a problem only of converting 110 volt, 60 cycle a.c. power to a hi-voltage unipolar d.c. voltage at very low current flow; 10-12 milliamperes in the ionizer and essentially no current flow in the collector.

The critical problem of radio interference has been solved by selection of the proper hi-voltage cable and connectors, and in some cases by the installation of copper screens on the inlet and outlet.

6. Cleaning

The third fundamental requirement is to remove collected dirt from the precipitator to an external waste receptacle. This has been accomplished on Navy equipment by incorporating a wash-in-place feature on all units except those designated for installation in the battery inlet. The washing system consists of a manually operated, rotating manifold on the inlet side of the precipitator, a quick disconnect fitting on the manifold (external to the precipitator), a detergent kit, and hose to connect to the ships potable hot water system. Numerous nozzles are spaced across the manifold such that all interior surfaces of the precipitator will be cleaned as the manifold is rotated. Any good, non-foaming detergent will yield satisfactory cleaning results as long as the water temperature is approximately 130°F or higher and the pressure is 30 psi at the precipitator. This last requirement means that on some submarines, the ships potable water system pressure must be increased during the cleaning process. The battery inlet precipitator is designed for removal of the collector cell for separate washing in the galley sink or ultra-sonic cleaner.

The wash-in-place concept was developed to conserve space, simplify cleaning, to insure that regular cleaning schedule would be maintained, and to allow installation in locations otherwise not suitable. Space is conserved by eliminating the manufacture of the collector cell in sections with the associated hi-voltage connector and air sneakage problems. In addition, less access space is required than that required if the collector cell had to be removed for cleaning.

The wash-in-place cleaning process will not clean the collector plates as thoroughly as, say, the ultra-sonic cleaner. However, there is nothing whatsoever to be gained by having the plates spotlessly clean.

Each precipitator is provided with a drain pan and piping such that the dirt, water and detergentare carried to the bilge.

7. Efficiency

High efficiency, while the goal for precipitators, is not the single governing design factor. It does, however, serve as an indicator of equipment design and quality, and its relationship to ozone production becomes increasingly important. Briefly, efficiency and ozone production go hand-in-hand, as high efficiency generally requires maximum corona discharge which in turn is partially responsible for ozone production. Therefore, a balance of efficiency and tolerable ozone production must be considered.

As a word of explanation, efficiency is determined using a dioctylphthalate (DOP) aerosol with a median particle diameter of 0.5-0.7 microns. Light scattering equipment is used to determine the efficiency by relating inlet and outlet particle counts.

8. Pre-Filter

To prevent large (greater than ten (10) microns) size particles from entering the precipitator a Navy standard type air filter is installed on the inlet. It is desirable to collect gross contamination on a mechanical (impingement) type filter rather than on the precipitator.

9. Ozone

The majority of the ozone produced in a precipitator is formed by the high energy breakdown of the oxygen molecule into two oxygen atoms, each of which recombine with an oxygen molecule. The ultra-violet light of the corona discharge is also responsible for a small part of the ozone. The equation should be as follows: $3\ O_2$ + electrical energy = $2\ O_3$. The mechanism for this reaction is not understood. However, it is apparent from experience that the following are the two major factors:

(a) surface area of the ionizer electrode

(b) ionizer current

The greater the surface area, the more electrons will be emitted and hence the more ozone produced. A similar situation is expected for

ionizer current, i.e., the greater the current the greater the energy transmitted into the electric field.

The Bureau of Medicine and Surgery has, within the past three (3) months, established a new M.A.C. for ozone of 0.05 ppm. The present generation for any precipitator is less than 0.1 ppm (the previous M.A.C.) and is closer to 0.07-0.08 ppm. Originally the Bureau considered even 0.1 ppm as acceptable since a very short half life (minutes) was expected; that is, even with this generation a very low ambient concentration would be expected. Recent experience indicates that the half life may run into 100 or more hours at these low concentrations.

Since the Research-Cottrell equipments have been installed in some submarines, ozone concentration above 0.05 ppm have been reported. In these cases the reduction of ionizer power to the very low settings has reduced the ozone concentrations. This power reduction also reduces efficiency to 85-90% from 97%.

Various ozone measuring techniques have been investigated. However, most of these do not have the sensitivity to be useful. The best available method is that developed by Naval Research Laboratory which uses a buffered potassium iodide solution to react with the ozone in the air sample to form iodine. A known quantity of sodium thiosulfate solution is injected and the time required to reach the end point is an indication of the ozone. This equipment, however, does not lend itself to operation onboard a submarine. An instantaneous method devised by the Mast

Development Company, while of sound principle, has failed in two shipboard tests. This equipment is compact and easily portable and therefore very well suited to submarine use if the "bugs" can be worked out.

The recent increase in knowledge of ozone and it's reactions leads the Bureau to consider the use of an ozone "getter" in each system containing a precipitator. The "getter" (any material which will react with ozone) considered best is carbon. However, items such as natural rubber have possibilities which must be explored. Continued investigations will establish the parameters for any ozone "getter". A parallel study will investigate possible methods of reducing ozone production in the precipitator.

10. Conclusion

The above has been an attempt to shed some light on electrostatic precipitators as air cleaners and in particular for submarine use. However, no effort has been made to be specific in detail about any one of the thirteen (13) designs for this application. This information combined with the technical manual (NAVSHIPS 338-0433) should suffice to answer any detailed question on a particular precipitator.

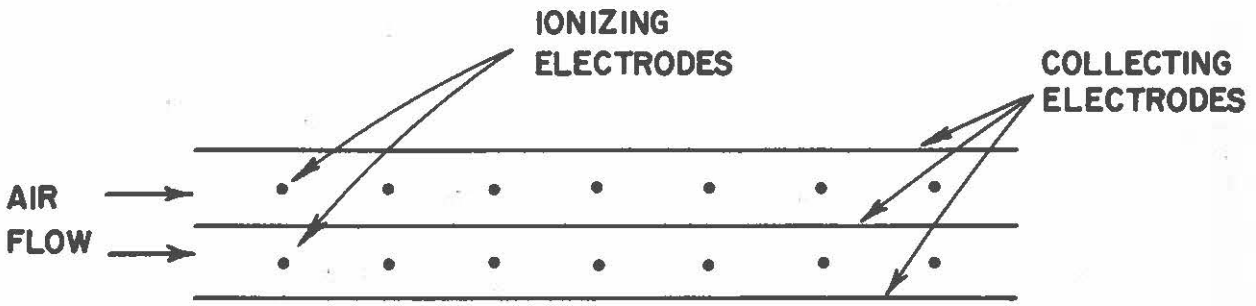


FIG. 5-1 SINGLE STAGE ESP

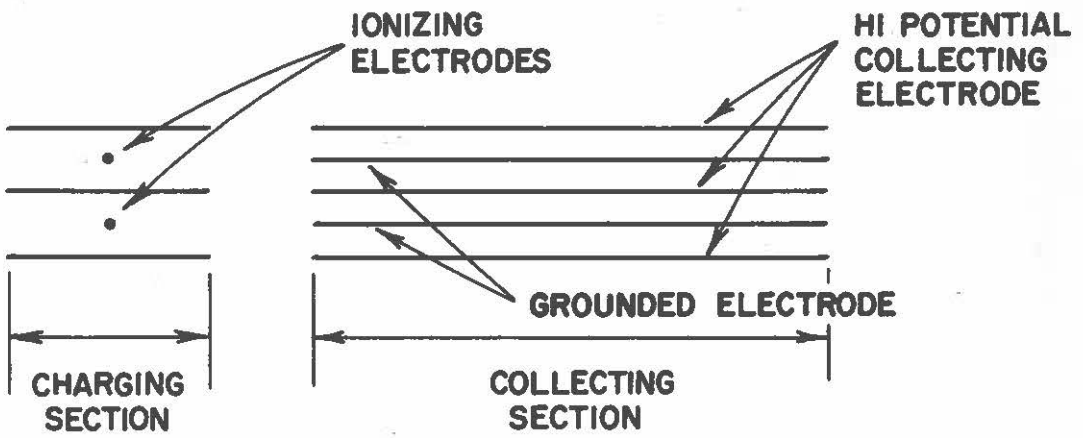


FIG. 5-2 TWO STAGE ESP

SECTION 6

TRACE CONTAMINANTS AND ODOR CONTROL

601 Purpose

This section discusses the need and the use of activated charcoal for controlling trace contaminants and odors aboard nuclear powered submarines.

602 Introduction

1. Nature of Activated Charcoal

a. Activated charcoal is charcoal or carbon prepared from nut shells, wood, coal or other carbonaceous material and activated by the use of steam at high temperature. The terms "activated charcoal" and "activated carbon" have almost the same meaning and for most purposes can be considered synonymous. The activated charcoal has an internal sub-microscopic sponge structure consisting of tiny capillary passages, thereby imparting to the charcoal the property of adsorption.

b. Any gas or vapor will, to some degree, adhere to any solid surface at ordinary (maximum of 125°F) or low temperatures. This phenomenon is called adsorption. In this process, gases and vapors (the adsorbates) are collected in a condensed state upon the surfaces of the solid which is called the adsorbent. These surfaces include not merely those comprising the exterior of the adsorbent, but also all the surfaces of the vast network of capillary passages.

c. Activated coconut shell charcoal has its adsorptive area in the form of capillary pores which can remove and retain all types of vapor impurities even though they are present in very dilute form. Certain other types of activated carbon (such as prepared from coal or wood) have much larger pores and do not have the power of removing the lower molecular weight materials from dilute concentrations. As a specific example of this, tests have shown that of all commercial activated carbons available, coconut shell charcoal does the best job in critical odor control problems. For these reasons, all activated charcoal used aboard nuclear powered submarines is manufactured from coconut shells.

2. Gas and Vapors versus Aerosols

a. Gas and Vapors: These terms define matter consisting of dispersed molecules which are diffused rather than suspended in air. This matter ranges in size from 0.00003 to 0.01 microns. The motion of molecules is the result of their collision and is influenced by temperature and pressure (Brownian Motion). Gaseous impurities in air account for odor sensations, air "staleness" and irritating or toxic effects.

b. Aerosols: The term particulate matter is commonly used to define aerosols. Particulate matter consists of dusts, smokes, mists and fogs. Dusts and smokes define inert solid

particles suspended in air while mists and fogs define inert liquid particles suspended in air. Aerosols are more fully discussed in other sections of this book and are only mentioned here to define the differences between gases and vapors, and aerosols.

c. Elimination of Gases and Vapors: Particulate matter is removed from the ships atmosphere by air filters and electostatic precipitators. These systems are fully discussed in other sections of this book. Gases and vapors are extracted from the ships atmosphere by the process of adsorption, the adsorbent in all cases being activated coconut shell charcoal. The means of accomplishing this extraction is discussed in the following paragraphs of this section.

3. WR & WC, Sanitary Tanks and Central Ventilation Systems:

a. WR & WC: Odor removal in these spaces is accomplished by installing activated charcoal purification units within the space. These units consist of a canister containing activated charcoal to which is attached a fan for circulating air through the canister. These units have not been entirely satisfactory in the past because of not being properly maintained or not being used at all by ship's force. Proper maintenance of the units, i.e., cleaning of the canister and replacement of the activated charcoal periodically, will provide satisfactory results.

b. Sanitary tanks: An activated charcoal filter unit is provided on the inboard vent line from all sanitary tanks. This filter is provided to remove odors when venting sanitary tanks inboard. Here again, proper maintenance of the filter is mandatory to insure satisfactory performance. This maintenance includes cleaning of the filter and periodic replacement of the activated charcoal.

c. Central Ventilation Systems: Unsatisfactory performance of the activated charcoal purification units led Bureau of Ships to believe that an improvement was needed for odor control in the WR & WC spaces. Therefore, on the later nuclear submarines beginning with the SSB(N)608 Class, a mechanical exhaust system will be provided from all WR & WC spaces. The amount of air to be exhausted from these spaces will be determined on a rate of change basis. A portion of the air supplied to these spaces will be by mechanical supply with the balance of the supply air being provided by natural supply. The mechanical exhaust will be discharged to the ship's main carbon filter where odors will be removed by the adsorption process previously described. The principle of operation for this exhaust system is the same as that for the galley and battery exhaust systems, common to all nuclear submarines.

4. Activated Charcoal Packaging

a. Bulk Carbon: The initial carbon filters installed onboard nuclear submarines consisted of a housing containing loose or bulk carbon. The carbon for filling these filters was provided in 55 gallon drums, which is extremely difficult to store aboard ship. Unloading and recharging the carbon filter was a tedious and undesirable chore, often consuming several hours of laborious work. Here again, Bureau of Ships and ship's force recognized the need for improvement in packaging and handling of activated charcoal.

b. Bagged Carbon: Mare Island Naval Shipyard was assigned an R & D Project with one of the objectives being to simplify the handling and the disposal of the carbon. As a result of this project, a standard carbon package has been established for use on nuclear submarines. This package, a cotton bag 12 inches by 8 inches by 5 inches with square corners, is one-half filled and contains approximately 5.2 pounds of carbon. This bag allows the carbon to be packed, almost as well as loose carbon, into beds of differing dimensions and also provides convenient handling and disposal of the carbon. The carbon in these bags is also used for recharging the WC filter units, sanitary tank vents and plumbing filter vents. The specification for this bagged carbon is MIL-C-17605A dated 29 February 1960;

"Charcoal, Activated, Technical, Unimpregnated." The packaged carbon may be obtained from the Submarine and Reactor Parts Supply Office under Stock Number PF 6810-726-7944.

5. Use of Paint and Solvents Aboard Ships

a. Tests conducted over a period of about two years (1957 to 1959) indicated that the carbon filters became saturated within two or three days after renewal. This was due to unrestricted use of paints and solvents aboard ship. As a result, Bureau of Ships Instruction 9190.40 of 20 April 1959 was issued. The subject of this instruction is reduction of atmospheric contamination on nuclear submarines and the purpose was to restrict or eliminate the use of several categories of material on nuclear submarines to reduce atmospheric contamination.

b. Solvents: The subject instruction eliminates all use of organic solvents, except for particular purposes and under conditions specifically prescribed by the Commanding Officer of each submarine. Use of solvents shall be permitted only where necessary for technical reasons and where no substitute is adequate. The Bureau shall be kept currently informed on the purposes for which use of solvents is permitted and the manner of use prescribed by the ships instructions. For general cleaning the following solutions are recommended in lieu of materials

such as Stoddards solvent: (1) Cleaning Compound - Specification P-C-431, Type I, Stock Number GF 7930-249-8035. (Mix 5 to 7 ounces in one gallon of water); (2) Wetting Agent - Specification MIL-D-16791, Type I, Stock Number G 7930-282-9702. (Mix 1 to 1 1/2 fluid ounces in one gallon of water).

c. Paint: The subject instruction requires that all major painting shall be completed on new and overhauling submarines thirty (30) days prior to departure for sea. Change Number 1 to subject instruction dated 17 July 1959 defines the date of departure for sea as the date of the first dive after departure for a period of operation. Dives made for the purpose of testing installations and checking work done, and which are to be followed by a dockside period before further operations, may be disregarded in establishing the painting schedule. The Commanding Officer of the submarine involved shall determine the "date of departure" as it relates to painting whenever the question arises. Touchup painting with oil based paints shall be accomplished only where necessary for preservation and shall be completed fifteen (15) days prior to departure for sea.

Interior painting accomplished less than 30 days before departure for sea shall be done with water based paint. Such painting shall be completed 72 hours before departure for sea. (Naval Research Laboratory is currently investigating water based paint for the purpose of deriving a formulation that

would allow touchup painting during ships operation. This formulation is yet to be evaluated aboardship and therefore any further discussion will have to appear as an addendum to this publication.

Exhaust ventilation to the weather at a rate of at least ten changes per hour shall be maintained during all painting and for at least 72 hours thereafter from any compartment in which any painting is done. No painting shall be done at sea except after the last dive at return from patrol

d. Fuel and Lube Oil: Fuel tanks shall be vented in accordance with the Force Commanders Instructions, and before the ship is finally sealed for an extended submergence. After fuel tanks have been vented, the air in the ship should be renewed with fresh air. Venting of fuel tanks should be avoided after the ship has been sealed for a long submergence. Engine and machinery surfaces shall be kept clean of fuel and lube oil using dry waste or detergent. Soiled waste shall be stored in covered receptacles and disposed of via the garbage ejector. Lube oil shall be handled and transferred via tanks and not via the bilges wherever possible.

e. Miscellaneous: Contaminants may be brought aboard in a most unforeseeable manner. For example, hobby handicraft kits obtained to occupy leisure hours on a long dive have proved to contain glues, paints, etc., which would release an

unacceptable contaminant into the ship's air when used. For example, serious eye irritation lasting one week on one submarine is believed to have been caused by formaldehyde produced from methanol in the CO burner heater and not oxidized in the catalyst because of a leak around the catalyst bed. The methanol presumably came from shellac. Only MIL-S-18000 shellac containing ethanol, not methanol, is approved for submarine use. Shellac, like paint, shall not be used when submerged. Such incidents can be prevented only by suspecting an air contaminant in everything brought aboard. Whenever doubt exists respecting any material which cannot be resolved locally, send a sample to the Bureau of Ships, Code 649, with a report of the circumstances and all information on the label.

6. Impregnated versus Plain Carbon

a. Impregnated: Activated charcoal impregnated with silver nitrate was provided as the material to be used in the carbon filter for SS(N)571, SS(N)575, and SS(N)578 Class. The initial battery installed on SS(N)571 contained grids made of an alloy consisting of lead, antimony (Sb) and arsenic (As), the same as is installed on diesel submarines. This battery evolves trace amount of AsH_3 at all times and SbH_3 when charging at the finishing rate. The silver nitrate was for the purpose of adsorbing the AsH_3 and SbH_3 evolved from the SS(N)571 battery. All SS(N)s subsequent to SS(N)571, and all battery renewals

have batteries that do not contain any antimony and only minute quantities of arsenic. Therefore, activated charcoal impregnated with silver nitrate is no longer required. The reason for putting this material aboard the SS(N)575 and SS(N)578 Class was simply an oversight on Bureau of Ships part. This oversight was rectified on subsequent SS(N)s. It is to be pointed out that the silver nitrate does not affect the adsorption capacity of the carbon; it only provides an affinity for AsH_3 and SbH_3. Another factor is that silver nitrate impregnated carbon costs about $2.25 per pound while plain carbon costs about $1.00 per pound.

b. Plain Carbon: As previously discussed, all carbon used aboard nuclear submarines is activated coconut shell charcoal. The reason this type of carbon is used is explained in paragraph 602-1.

603 Principle of Operation

1. Carbon Filter Arrangement

a. All SS(N)s from SS(N)571 through SS(N)592 have two carbon filters, one located in the galley exhaust system and one located in the fan room arranged so as to pass the battery exhaust and return air from aft through the filter during submerged operation. The galley exhaust unit extracts odors generated by cooking and the fan room unit extracts odors and

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trace contaminants that are present in the ship's atmosphere. The carbon filter in the fan room is a relatively small unit, perhaps on the order of two square feet, and contains bulk or loose carbon. A SHIPALT to increase the size of the carbon filter will be issued in the near future.

b. Specification for Building SS(N)593 Class, SSB(N)608 Class, and SSB(N)616 Class submarines specify a carbon filter with a filter bed not less than four (4) inches deep arranged for charging with carbon in standardized packaging. The main objectives of these carbon filter requirements are:

(1) To increase the amount of carbon contained in the filter.

(2) To simplify the charging of the filter

(3) To simplify the handling and the disposal of the carbon.

Design requirements for the filter are as follows:

(1) Vertical bed

(2) 10% settling space at top of filter

(3) Access door to settling space so that additional carbon may be added to compensate for settling within the bed.

(4) Use of Navy Standard Type air filter on inlet side of the carbon bed.

(5) Velocity through filter - 125 fpm maximum

(6) Airflow through filter - 1000 CFM minimum, as much more as is practical

A vertical filter is required for the following reasons:

(1) A horizontal installation permits inevitable points of loose packing to be agitated by the air flowing through the filter. This results in progressive and accelerated break down of the carbon particles, eventually resulting in almost complete bypass. In the vertical arrangement, the pressure of the carbon above automatically compensates looseness of packing as fast as it occurs.

(2) Ease of charging the filter bed

(3) Less space required for charging

Stowage aboard ship for spare carbon to recharge the filter bed shall be provided. The total amount of carbon supplied, including the carbon contained in the filter, shall be based on one pound of carbon for each 75 cubic feet of the ship's floodable volume. In addition, stowage shall be provided for spare carbon that is required to service the WC filter units, the sanitary tank vents and the plumbing filter vents where applicable.

2. Effect of Dirt

Activated charcoal does not remove ordinary particulate matter such as dust or dirt. However, presence of particulate matter will tend to clog the capillary tubes in the carbon

thereby reducing the capacity of the carbon for adsorption of gases and vapors. It is of prime importance that the mechanical filters employed on the inlet to the carbon bed be kept clean of dirt, dust,and lint.

3. Activity and Retentivity

a. Activity: The capacity of a sorbent for particular gas or vapor is called its "activity". It may be measured in several ways, one of which is to expose a sample of the sorbent to a stream of the particular vapor, under selected standard conditions of temperature and partial and total pressure, until the sorbent reaches equilibrium with the sorbate. This method determines the maximum possible adsorption of the respective gas or vapor by the carbon at the specified conditions, and the "activity" is then taken to be the ratio of the weight of sorbed substance to the weight of the carbon.

b. Retentivity: The retentive capacity of a sorbent, called its "retentivity", is more important than its activity because it represents the practical saturation limit of the sorbent under conditions common to ventilation. It is measured by passing clean dry air at constant pressure and temperature continuously through a bed of granular carbon previously saturated with a specific gas or vapor and continuing the air flow until the carbon ceases to decrease in weight. This method determines the weight of the respective gas or vapor that the carbon will

retain when exposed to clean air at specified conditions. The "retentivity" is then taken to be the ratio of the weight of the retained substance to the weight of the carbon.

Because carbon which is saturated in excess of its retentivity releases the excess sorbed substances when exposed to air, the retentivity is the criterion of its duration of effectiveness in air purification application. Retentivity will, obviously, vary depending upon the nature of the air-entrained impurities. Capacity or general retentivity values of activated coconut shell charcoal for some vapors are listed in table 6-1.

604 Operating Experience

1. Carbon Life

a. Attempts to determine the life expectancy of carbon beds have been based on data obtained with the Dorex canister type of carbon sampler by Naval Research Laboratory and by observations made onboard two operating nuclear submarines in connection with the "Fleet Assist Project"* by personnel from Bureau of Ships and Naval Research Laboratory. Using basic assumption and extrapolation between the Dorex canister and the ship's carbon bed, Naval Research Laboratory has estimated that the life expectancy of the carbon bed is about 25 days per 10 cubic feet of carbon when the hydrocarbon concentration in the ship's atmosphere is 5 ppm. It is emphasized that this is only an estimated life expectancy. Results of limited studies conducted by Naval Research Laboratory personnel on board USS HALIBUT, reported by reference (a), show that the efficiency of the carbon bed remained high throughout a 66 hour closed boat period. During the period the concentration was 2.0 to 3.5 ppm of combustible expressed as decane. Despite these very low concentrations, it was possible to establish the levels both before and after passage through the carbon bed. Because of the short period of time and low hydrocarbon concentrations, nothing conclusive can be stated as to the life expectancy. Atmospheric

* Project F/R32, "Assist the Bureau of Ships in Continuing a Nuclear Powered Submarine Atmospheric Habitability Test Program".

habitability studies conducted aboard USS TRITON in connection with the "Fleet Assist Project" and reported by reference (b) resulted in the following:

"USS TRITON has about 8 cubic feet of activated charcoal that processes atmospheric air with the largest single filter of 4 cubic feet located in the fan room. The fan room filter was changed the day before departure. In an effort to reduce the level of atmospheric freon, it was changed again on the 7th day of the 26 day dive. To investigate its usefulness, it was removed for the last 5 2/3 days. Inlet and outlet readings across the bed were taken at various times with a Davis halide meter, a Perkin-Elmer hydrocarbon detector, and various portable instruments. From these measurements, it appears that the carbon bed has a very short life (3-4 hours) for removing hydrocarbons and freon. The capacity for freon concentration about 80 ppm. No adverse effects or changes in hydrocarbon concentrations were evident during the 5 2/3 days the filter was removed. However, chemical analysis of samples taken before and during the "no-carbon" period and at the time the fan room filter was changed should provide more quantitative data. At least tentatively, it appears that contaminant and odor control can be accomplished with CO burners plus only a small amount of carbon."

From these three examples, it is apparent that the life expectancy of carbon beds cannot be definitely stated. In an effort to establish ground rules for the life expectancy of carbon, the Bureau is currently working with Naval Research Laboratory on a program to provide the operators with a method of determining when it is time to change the carbon bed. It is anticipated that nuclear submarines will be requested to participate in this program to the extent of "trying out" the method under actual operating conditions.

b. In conclusion, the Bureau maintains that activated charcoal does serve a useful purpose aboard ship, in spite of some contrary reports, but we do recognize the need for more research and development in this area. It is Bureau of Ships intent to pursue this problem to the fullest extent possible.

605 Future

1. Research and Development

a. Bureau of Ships intends to conduct a research and development project for the purpose of investigating the feasibility of reactivation-in-place of activated charcoal. This will have several advantages such as:

(1) Smaller carbon filters

(2) Stowage for spare carbon to recharge the filter bed, perhaps only during overhaul periods.

(3) Less frequent recharging of the filter bed, perhaps only during overhaul periods.

Because preliminary investigation only has been made, this project cannot be discussed in detail at this time.

REFERENCES

(a) Naval Research Laboratory ltr report 6180-2A:MEU:ech of 5 January 1961

(b) Bureau of Ships Report on Travel SSR(N)586 Ser 649B-2761 of 5 November 1960

TABLE 6 - 1

Capacity for Coconut Shell Charcoal

2 - Acetaldehyde	1 - Carbon Dioxide	3 - Hydrogen Sulfide
4 - Acetic Acid	1 - Carbon Monoxide	4 - Isopropyl Alcohol
3 - Acetone	4 - Carbon Tetrachloride	4 - Masking Agents
3 - Acrolein	3 - Chlorine	4 - Mercaptans
4 - Alcohol	4 - Chloropicrin	4 - Ozone
2 - Amines	4 - Cigarette Smoke	4 - Perfumes, cosmetics
2 - Ammonia	4 - Cresol	4 - Perspiration
3 - Animal Odors	3 - Diesel Fumes	4 - Phenol
3 - Anesthetics	4 - Disinfectants	2 - Propane
4 - Benzene	4 - Ethyl Acetate	4 - Pyradine
4 - Body Odors	1 - Ethylene	4 - Ripening Fruits
2 - Butane	4 - Essential Oils	4 - Smog
4 - Butyl Alcohol	2 - Formaldehyde	3 - Solvents
4 - Butyric Acid	4 - Gasoline	4 - Stuffiness
4 - Cancer Odor	4 - Hospital Odors	4 - Toluene
4 - Caprylic Acid	4 - Household Smells	4 - Turpentine

The capacity index has the following meaning:

4 - High capacity for all materials in this category. One pound takes up about 20% to 50% of its own weight - average about 33-1/3%. This category includes most of the odor-causing substances.

3 - Satisfactory capacity for all items in this category. These constitute good applications but the capacity is not as high as for Category 4. Adsorbs about 10 to 25% of its weight - average about 16.7%.

2 - Includes substances which are not highly adsorbed but which might be taken up sufficiently to give good service under the particular conditions of operation. These require individual checking.

1 - Adsorption capacity is low for these materials. Activated charcoal cannot be satisfactorily used to remove them under ordinary circumstances.

SECTION 7 - ATMOSPHERE ANALYSIS

Part I - Monitoring Equipment

701 INTRODUCTION

1. Atmosphere Analyzers

Toward the end of World War II, thinking and action were started toward finding answers to the apparent problems of submarine atmosphere control for the continuous long submergences which were certainly coming sometime in the future. Up to that time essentially all submarine atmosphere control had been intended for emergency use with routine control by ventilation to the outside atmosphere.

It was realized that there would be need to continuously monitor the presence of certain components in the submarine atmosphere necessary to or resulting from the respiratory requirements of the personnel. There were also components which would require monitoring to ensure the safe operation of the ship. The principal of these were concluded to be carbon dioxide (CO_2), oxygen (O_2), carbon monoxide (CO), hydrogen mixture of ill defined composition. Study of the conditions surrounding this application made it appear desirable to utilize, if possible, the physical characteristics of these gases for analysis instead of the usual chemical analysis methods and to employ methods resulting in an electrical signal indication so that simple recording could be provided.

Consideration was given to several unified methods of gas analysis, such as the radio frequency mass spectrometer, and some work was carried out on them without producing promising results.

Examination of available physical gas analysis methods resulted in the selection of the positive filter method of infrared (IR) spectroscopy as being the only method suitable or potentially suitable for the very low concentration of CO which had to be determined. This method would also be usable for the CO_2 and the hydrocarbon. The need for an oxygen analysis method could be satisfied by use of equipment utilizing the distinctive paramagnetic property of oxygen. The accuracy required for the H_2 analysis was sufficiently low as to permit the use of the thermal conductivity method.

The first unit produced under this concept was the Mark I Atmosphere Analyzer which, although installed aboard the NAUTILUS for a time, was never operated as shipboard equipment. It utilized a combined IR portion for CO, CO_2, and a generalized hydrocarbon analysis, a paramagnetic oxygen unit of the Pauling type with electrostatic balancing, and a simple thermal conducitivity unit for hydrogen. Indications were brought out both to panel meters and to an electronic strip chart recorder. The entire gas sample system was operated at essentially ambient pressure with a separate small pump for each sample location.

Mark I was replaced in a very short time by the Mark II. In this unit the O_2, H_2, sampling and recording portions were essentially the same as in the Mark I but the three IR analysis channels were made into completely separate units. The packaging of the assembly was drastically redesigned and improved. As a result of the operation of the several Mark II analyzers which were installed and operated, a number of changes were seen as desirable or necessary. Principally these were: greater sensitivity of the CO unit, removal of the recorder, elimination of the hydrocarbon channel due to its unsuitability for the intended purpose, and the need for procurement of analyzers, parts and service from a commercial source. (The unsuitability of the hydrocarbon channel resulted from an overriding indication from the relatively large concentration of methane present in the submarine atmosphere.)

All these changes were included in the Mark III. The hydrocarbon channel was easily changed to a Freon 12 analyzer for which there was a need. The desired additional sensitivity of the CO analyzer was obtained by increasing the gas sample pressure in that unit to 100 psi gauge. By also using this pressure in the Freon channel it, too, was made quite sensitive. This pressurized system required a single sample pump and the present pump was designed and built for this job since no

suitable commercial pump could be found. The unit was considerably repackaged but still was basically the same as Mark I and II.

The Mark III has gone through "growing pains", particularly in the pump, both before and since its first shipboard use. As time passed, the need became apparent for a number of changes which would improve the unit. These originated mainly from service operating personnel, from the manufacturer, NRL, and Bureau personnel. The backfit applied to the Mark III was intended to apply all the worthwhile improvements and remove the sources of trouble which had been made known to the Bureau.

2. Portable Atmosphere Monitoring Units

Although the Mark III should be the normal analysis means for the atmosphere components which it determines, there are present on the ships other means for determining most of these atmosphere constituents. These, in general, are the portable, individual units, chemical or physical in basis, which appeared aboard the fleet submarines to meet the requirements for emergency use. These included for oxygen the Beckman visual indication paramagnetic oxygen analyzer, for CO_2 the Dwyer unit which absorbs CO_2 in a potassium hydroxide solution, for CO the NBS colorimetric tube type unit, and for H_2 abd hydrocarbon the MSA and Davis units which utilized the catalytic combustion on a hot filament. It should be noted that there is no available, suitable unit for Freon concentration.

These units have a definite place in the requirement for atmosphere control as a back-up for the Mark III when it is out of commission, for occasional verification, and for special locations and circumstances.

702 PRINCIPLES OF OPERATION

1. The Mark III Atmosphere Analyzer

The basic principles of operation of the various parts of the Mark III are extensively described in section 5 of NAVSHIPS 338-0350, the technical manual for this unit. Because of the length of that explanation it appears desirable to give here a brief and much simplified description of the principles underlying the several major portions of the Mark III.

The analysis elements are, of course, the basic portions of the Analyzer. The Freon, CO, and CO_2 units are fundamentally identical. Each of these gases has a distinctive absorption spectra in the infrared light region. The basic principle of the IR analysis and its visible light equivalent is shown in Figure 7-4. When IR energy from a suitable source, such as a barely glowing filament, passes through a gas sample, the presence of one of these materials will remove only certain very definite portions of the energy spectrum. The proportion of energy removed is dependent on the quantity of the absorbing material present. The energy leaving the gas sample is determined by an inherently

highly selective energy receiver which is a very pure portion of the gas to be determined. This gas is hermetically sealed into a cavity containing an IR transparent window to allow the entry of the entire energy spectrum. The energy absorbed by the gas in the receiver causes a pressure increase in the gas which is compared, by a pressure sensitive diaphragm, to the pressure produced by the absorption of energy from an identical IR source, sample tube, and receiver assembly in which the sample tube is sealed and contains none of the gas component being determined. In order to make the receiver in the IR system independent of most ambient condition variations, the energy flow from the sources is interrupted by a motor driven shutter at about 10 cycles per second. The pressure difference when converted into an electrical equivalent and with suitable amplification and rectification provides a gas concentration indication on a meter.

This IR system is very similar to a visual light measuring system in which a beam of light from a light source, such as a light bulb, passes through a colored glass into a phototube which is sensitive only to the color absorbed by the glass. The output of the phototube is compared to that from an identical light system which contains no colored glass. The difference between the two phototube outputs is a function of the absorbing power of the colored glass.

The oxygen analysis unit (Figure 7-2) makes use of the unique property of oxygen of being the only common gas which is strongly attracted into a magnetic field. This unit has a tiny test body movable in a strong, highly divergent magnetic field.

The gas sample to be determined is allowed to diffuse into the space containing the magnetic field and test body. Any oxygen in the sample tends to move into the strongest part of the magnetic field and to push the test body out with an amount of force dependent on the amount of oxygen present. This push on the test body is balanced by an opposing electrostatic force to keep the test body in an unchanged position. An optical and electronic system which is sensitive to the test body position produces the potential necessary to give this restoring force. This potential provides an oxygen concentration indication on a meter. This entire system is comparable to a wood block floating on water. If the water level is raised the wood block can still be maintained in its original position if a suitable force is applied. The amount of the force can be used to determine the rise in water level.

The hydrogen analyzer (Figure 7-3) makes use of the high thermal conductivity of hydrogen gas. Basically, a heated body (filament) with constant heat input is so placed in the gas sample that it can only lose this heat to a constant temperature heat sink through thermal conduction of the gas sample. When the gas sample contains no hydrogen the filament attains such a temperature that the fixed input of heat will pass to the sink. When hydrogen is present in the gas sample the thermal conductivity of the gas is drastically increased and a smaller temperature difference between the filament and the heat sink will still pass

the fixed input of heat. A lower filament temperature results. By using the change of electrical resistance of the filament with its temperature change a gas concentration indication for hydrogen can be produced on a meter. In the normal range of concentration variation of the submarine atmosphere only the hydrogen appreciably effects the thermal conductivity of the gas sample.

In the Mark I and II units, the sampling system was relatively simple since these units operated at ambient pressure. In Mark III, however, to gain sufficient sensitivity in the CO and Freon channels, it is necessary to operate these portions at 100 psig. The sampling pump draws the gas sample from remote location and compresses it into about 1/7 of its original volume. This pump bears considerable similarity to a simple two cycle gas engine. On cooling the compressed gas, there is normally excessive vapor present which separates as liquid water in a water trap from which it is dumped by a solenoid valve. The pressure regulator is placed after the Freon and CO channels so that the gas sample is maintained at 100 psig in those channels. A solenoid valve parallels the pressure regulator so that the Freon and CO channels can be operated at ambient pressure to provide the 3000 ppm range on the Freon unit. The CO_2, O_2, and H_2 analyzers operate on the essentially ambient pressure output from the regulator. Solenoid valves, check valves and a hand vacuum pump are contained in the sampling system to permit evacuation of the system which

results in a zero concentration indication on the analysis units. The hydrogen unit is not evacuated since it does not produce a zero indication but only a large off-balance signal at very low pressure.

2. Portable Analysis Units

Of the several portable, individual analysis units on the submarines, only the oxygen analyzer employs the same basic principle as that used in the Mark III unit. In the portable oxygen unit there is however, no electrostatic force restoring the test body to the null position but, instead, the force opposing the movement of the test body is the torque developed by twisting of a quartz fiber. The indication of oxygen concentration in this unit is the position assumed by the test body as a result of the balance of forces between the oxygen pushing the test body out of the magnet field and the torque of the fiber pushing the test body into the magnetic field. This position is shown as a light spot on a scale by reflection of a light beam from a small mirror attached to the test body.

The Dwyer CO_2 unit operates by first trapping a fixed quantity of gas sample in a chamber. This trapped sample is exposed to a potassium hydroxide solution which results in the complete removal of the CO_2 by chemical reaction. This removal reduces the volume of the trapped gas sample and the amount of

this volume change and hence the concentration of CO_2 is indicated by movement of the absorber liquid into the sample space.

The portable CO analyzer is based on a color producing reaction between CO and a yellow chemical, a complex silico-molybdate compound catalyzed by palladium sulfate, carried on silica gel. The analysis is carried out by opening both ends of the sealed tube containing the prepared reagent and drawing a known volume of the gas sample at a given rate through the tube. CO contained in the gas sample reacts with the yellow reagent to give a green color. The color is compared to a color chart and the extent of color change is dependent on both the CO concentration and the amount of gas flow (number of squeezes of the rubber aspirator bulb).

The portable H_2 analyzer is basically a combustible gas detector and operates on the same principle as commercial instruments for detecting explosive mistures of gases and vapors. For hydrogen, a platinum filament is operated at a sufficiently elevated temperature to be catalytically active for combustion of hydrogen on its surface. When the filament is exposed to a gas sample containing oxygen and hydrogen, the combustion which takes place on the surface of the filament raises the temperature of the filament. The change of electrical resistance resulting is used to produce a meter indication which is related to the amount of combustible material present in the gas sample. The instrument is not specific for hydrogen but, in submarine use, other combustible materials are present in such small quantities normally that they do not interfere.

703 OPERATION

1. Mark III Analyzer

It was intended originally that the Analyzer would operate continuously and that it would be lighted off sufficiently in advance of use to permit its reaching full equilibrium with its surroundings. However, fleet experience has shown that there is no normal need for the moving, wearing parts of the unit to operate except during the actual period of taking readings, usually at from 1 to 4 hour intervals. Panel switches are therefore provided to secure the pump and chopper motors between readings.

Calibration with the compressed calibration gas should be limited, so far as practicable, in order to keep the use of this material to a reasonable quantity. No calibration should be attempted before the analyzer has been operating a sufficient time to reach a stable condition. The vacuum zero and test signals provided should permit verification of the unchanged operation of the analyzer for a considerable period following a gas calibration. If an adequate log is maintained of the indications obtained under these various test conditions, it is possible to determine the extent of any change in analyzer operation since the last gas calibration. Such records are also valuable as a diagnostic aid by showing the direction and rate of any continuing change in the equipment.

The Analyzer should not be expected to produce an overall accuracy which is not built into it nor necessary to the ship's operation. There are limited permissible effects in both the span and zero due to such variables as temperature, pressure, aging of components and crossover indications from other gases present. When the unit is allowed to equilibrate to its surrounding conditions, the indications become stable although they may be somewhat in error. The amount of this error can be determined by calibration. These indicated values are essentially as useful as though they were absolutely correct since the error is known and changes from the satisfactory atmosphere condition are clearly exhibited. Opening of the case for frequent, and often inconsequential, adjustment can only lead to upset of the equilibrium and indication errors which persist until that equilibrium is again attained.

A considerable number of specific trouble sources and suggested improvements have been reported by operating personnel from service use, particularly for a few of the units. These have been corrected by application to the previously manufactured units of an updating backfit kit furnished under NObs 76747 and 76748. There are considerable advantages resulting from suitable installation of the backfit.

Much of the service experience with the Mark III has been reported in vague and generalized terms. These indicate large differences in the experience of the various ships in operating the units, but provide little basis for corrective action. The Bureau desires specific factual information on sources of troubles and suggested improvements apparent as the result of service use. This will permit further remedial measures if required.

Being a complex piece of equipment, diagnosis of malfunction can be a very time consuming process, especially for operating personnel who have not thoroughly studied the instruction manual and learned and worked with the actual analyzer ahead of the time when there is a "fire-drill" to get it back in operation.

Repeated difficulties in a particular operating area or part of the analyzer should not be indefinitely tolerated since they may indicate a need for correction in the nature of a change of material or redesign of a part. This correction can only occur if the failures are reported. Further, such troubles may be the result of a fault or derangement elsewhere in the system, and for this, service help is available when necessary and the facts are suitably reported to the Bureau.

Cooperation of operating personnel in returning replaced major parts to the Bureau, particularly IR source assemblies, IR receivers, and oxygen analysis elements is requested in order to permit laboratory diagnosis

and corrective action if required.

2. Portable Analysis Units

Operation of the portable Beckman O_2 unit is quite obvious and requires no explanation.

The Dwyer CO_2 unit can produce reasonably accurate concentration values if it is operated and maintained carefully. The absorbing liquid must be replaced at the required intervals since it is chemically expended in carrying out the analysis. Trapping of the sample while the gas is flowing rapidly, excessive (more than 3) and rapid operation of the absorber plunger, holding the body of the unit with the hand during analysis, liquid on the gas valves, pressure change in the ship, and tilting of the unit can all produce various amounts of error in the indicated result and should be avoided. The usable result should be the average of at least three analyses.

The NBS type CO color tube unit has only a few precautions in operation but at the low concentrations of CO in the submarine atmospheres, the results are at best open to question. The number of squeezes of the aspirator bulb must, of course, be correct. A few seconds time must be allowed after the bulb has

apparently filled to complete the sample draw. The time for the bulb to fill must be as specified since the analysis is sensitive to the time of exposure to the gas sample. Excessive leakage of the vent valve must be avoided. The delicate change in color attained at low concentration is difficult to compare with the color chart provided and may appear quite different under various lighting conditions and to different people who may be, to various degrees, slightly color blind. There is at least one known interfering gas to this reaction, NO_2, so that an indicated CO concentration may be somewhat in error due to this cause. Despite these limitations, the CO tube will clearly indicate an excessive CO concentration condition.

704 Present Developments

There is in the later stages of development at this time a completely redesigned Atmosphere Analyzer, the Mark IV. Almost its only relationship to the present Mark III is that it still utilizes the same physical characteristics of the several gases as the basis for the analysis methods. Beyond that, the design has been drastically modified to remove, so far as possible, the various sensitive areas in the Mark III. After service use and test, the Mark IV will be procured for new construction. Replacement of Mark III by Mark IV is not contemplated.

The manufacturer of the Mark III and IV is continually carrying on an improvement program in those areas of the equipment which appear troublesome, especially as they apply to his industrial applications. A completely different two stage pump, possibly applicable to the Mark III, is under separate study.

A portable colorimetric tube type CO analyzer which gives a length of color change indication is under study as a possible replacement for the present NBS type unit which has a difficult-to-read uniform color change.

Other improvements, modifications, and replacements for the various atmosphere composition monitoring equipment can be expected as the need becomes known and the suitability of the proposed action is established.

Part II - Checking

705 INTRODUCTION

An assembly of semi-quantitative instruments is carried by all nuclear powered submarines to provide operating personnel with a means of investigating unusual occurences affecting atmospheric habitability during a patrol. The nucleus of this assembly, at present, is the Draeger Gas Detector Kit, manufactured in Lubeck, Germany by Draegerwerk. This kit belongs to a class of industrial hygiene, field-type instruments which may be operated by relatively untrained personnel to make semi-quantitative measurements of a number of industrial air contaminants and, therefore, it is not directly related to submarine requirements and standards. Draeger equipment was selected on the basis of being the first and only assembly of detector tubes which operated with a single pump and measured a number of materials. However, other manufacturers are now entering the field and, where desirable, the Draeger Kit will be supplemented and modified as the result of current Public Health Service evaluations. (*1)

706 TECHNICAL DESCRIPTION

The current list of Draeger tubes is given under "Stock Numbers". All tubes are based on the principle of color change which is applied as (1) color matching, (2) length of stain, or (3) first indication of stain. In general, length of stain is

(*1) Refer to References at end of text.

the preferable technique since it reduces errors due to varying illumination and operator color perception. Although the same pump is used with all tubes, each tube type has individual instructions supplied in each package which must be carefully followed.

707 OPERATING EXPERIENCE

Draeger Gas Detector equipment was first tried in submarines on the USS NAUTILUS (SS(N)571) "habitability cruise" in 1956.(*2) It has since had considerable operational use in nuclear powered submarines but results and methods of use have been quite varied - from a complete analysis several times a week to no use at all on a cruise. However, this is to be expected since it is provided as a reserve capability for use in investigating unusual circumstances. This type of equipment has insufficient sensitivity and specificity for studying the normal composition of submarine atmospheres.

708 STOCK NUMBERS

Draeger Gas Detector Pump	PF-6665-711-1767
Draeger Gas Detector Tubes	
Alcohol 0.2	PF-6665-769-0930
Ammonia 0.01	PF-6665-769-0932
Arsine 0.05/A	PF-6665-769-0942
Benzene 0.05	PF-6665-769-0943

Toluene 25/A	PF-6665-769-0944
Carbon Dioxide 0.5%	PF-6665-769-0945
Carbon Dioxide 1%	PF-6665-769-0948
Carbon Disulphide 0.04	PF-6665-769-0946
Carbon Disulphide 1%	PF-6665-769-0947
Carbon Monoxide 0.001%	PF-6665-769-0949
Chlorine 1/A	PF-6665-769-0950
Formaldehyde 0.002	PF-6665-769-0952
Hydrogen Sulphide	PF-6665-769-0953
Hydrocarbons 0.1%	PF-6665-769-0954
Hydrocarbons 2	PF-6665-769-0955
Mercury Vapor 0.0001	PF-6665-769-0956
Nitrous Gases 0.005	PF-6665-769-0957
Phosgene 1/A	PF-6665-769-0958
Prussic Acid 0.002	PF-6665-769-0959
Sulphur Dioxide 0.01	PF-6665-769-0960
Trichloroethylene 0.1	PF-6665-769-0961

REFERENCES AND BIBLIOGRAPHY

1. BUSHIPS Project Order 713 of 9 March 1959 with Occupational Health Research and Training Facility, Department of Health, Education, and Welfare, Cincinnati, Ohio

2. BUSHIPS Report on Travel (CONFIDENTIAL) SS(N)571 (549A), P16/Gates, A.S., Ser 549-036 of 18 June 1956

SECTION 8

EMERGENCY AIR BREATHING SYSTEM

801 Introduction

Facilities provided in nuclear powered submarines for routine atmosphere control are not necessarily adequate for the casualty situation where unusual quantities or types of contaminants are introduced. This situation is exemplified by a fire in which smoke and carbon monoxide (CO) are the main contaminants but a limitless number of other possibilities exist from decomposing plastics, paint, textiles, etc.. Although traditional submarine practice is to isolate the casualty, surface, and ventilate, this is impractical for under-ice operations and for certain tactical situations. The present solution to this problem was first suggested by USS NAUTILUS (SS(N)571) (*1) prior to her first Polar transit and consists of providing means for personnel to breathe from the ships high pressure air banks using full-face air line respirators. While this is not a complete solution to a toxic gas casualty, it does provide a 24-48 hour period to accomplish air cleanup or ventilation.

Partial installations were hastily made in USS NAUTILUS and USS SKATE (SS(N)578) prior to their first Polar trips and complete systems are now provided for all present and future nuclear powered submarines. The system is also being considered for battery powered ships at CNO's request. Present specifications

(*1) Refers to References at end of text.

are largely the result of discussions with operating personnel, especially USS SEAWOLF (SS(N)575) (*2) in 1958, but have been modified on the basis of tests in USS SKATE (*3) and USS TRITON (SS(N)586)(*4).

802 Technical Description

The system consists of full-face masks with demand regulators for all hands plus piping to permit ready access of filtered bank air for personnel at battle stations, watchstanders, and off-watch personnel. The following are the general characteristics of the system, based on specifications for SSB(N)616 Class submarines (*5).

air supply: from 100 psig system through filters (carbon + particulate filter)

outlets:
a. for 50% of complement in 3 assembly areas
b. for all battle stations
c. in duplicate at each watch station
d. in quadruplicate in all fore and aft passageways at intervals of not more than 20 feet and on both sides of all watertight doors
e. totalling 12 in wardroom
f. all outlets of quick disconnect type

masks: a. full face with demand regulators and 8 feet of attached hose for 140% of complement

b. auxilliary quick disconnect fitting adjacent to demand regulator (planned but not yet accomplished)

hoses: a. of sufficient length at each watch station for normal duties

b. ten hoses 25 feet in length for making up various longer lengths

c. two extension hoses with quadruple outlets on one end

d. all hoses with quick disconnect fittings

Operation of the system is based on separation of the ship's total air bank installation into separate banks which are "clean" or "dirty" plus periodic pumpdowns of the atmosphere with the high pressure air compressors (HPAC's). Air is supplied to personnel from "clean" banks (i.e., those charged prior to casualty) and the HPAC's discharge contaminated atmospheric air into "dirty" banks. For the first pumpdowns, it may be necessary to empty one bank by discharging overboard although some air may be saved by operating the ship at an elevated atmospheric pressure initially. Tests by USS SKATE (*3) gave an air consumption rate of 0.6 scfm/man for a six hour drill involving all hands. Using

this, or the more conservative value of 1.0 scfm/man, each ship can estimate its endurance with this system. Bureau estimates indicate a minimum of 24-48 hours for nuclear powered submarines.

803 Operating Experience

Evaluation tests of this system have been conducted aboard USS SKATE (*3) and USS TRITON (*4). USS SKATE tests included a drill in which all hands participated and the ship was operated submerged for a period of six hours. Communication problems were investigated, different mask configurations and pressure-demand regulators were evaluated, and the suitability of low humidity bank air for breathing was determined. USS TRITON tests included drills to (1) further investigate communication problems, (2) evaluate experimental mask configurations and the use of smaller diameter air hose and extension hoses, and (3) investigate problems of damage control parties moving abou the ship.

Operational use has been very limited and the Bureau is aware of only one incident (in USS SWORDFISH (SS(N)579)) in which masks were used because of a toxic gas casualty. USS GEORGE WASHINGTON (SSB(N)598) has been evaluating portable commercial loudspeaker assemblies (Stentorite Mark II) to facilitate man-to-man communications. Although such devices did not appear necessary in USS SKATE and USS TRITON tests, USS GEORGE WASHINGTON (on the basis of short drills) feels that they should be provided for certain personnel (CO, XO, etc.)(*6)

804 Stock Numbers

1. CS-Special - MSA Demand Type Air Line Respirator; similar to CS-78315, with Speaking Diaphragm, All-Vision Facepiece: complete with Breathing Tube, and Coupling Nut (less CS-81070, Single Stage Demand Regulator)
2. CS-81070 - Single Stage Demand Regulator; with tube insert and male section of quick disconnect fitting.
3. P/N 1591-XX - Air Hose, 8 feet long; with quick disconnect fittings compatible with MSA part nos. CS-55597 - CS-55716
4. CS-85571 - 5/16" I.D. Air Hose, 25 feet long; with CS-55597, female disconnect and male CS-55716 disconnect.
5. CS-47370 - 4-man Manifold; with automatic shut-off outlets.
6. CS-81857 - Air Line Filter, complete.
7. CS-46727 - Chemical Cartridge refill (for CS-81857 - 2 per refill required).
8. CS-73921 - Particulate Filter refill (for CS-81857 - 1 per refill required).

Items 1, 2, 4, 5, 6, 7, and 8 available from Mine Safety Appliances Company, Pittsburgh 8, Pennsylvania

Item 3 available from Globe Industries, Inc., 125 Sunrise Place, Dayton, Ohio.

REFERENCES AND BIBLIOGRAPHY

1. Conference between CDR W.R. Anderson (CO, USS NAUTILUS) and Mr. W.E. McConnaughey (BUSHIPS/649) in March 1958.

2. Bureau of Ships Report on Travel (CONFIDENTIAL), Ser 649B-045 of 1 December 1958.

3. Bureau of Ships Report on Travel SS(N)578, Ser 649B-1619 of 21 June 1960.

4. Bureau of Ships Report on Travel SSR(N)586), Ser 649B-2761 of 5 November 1960.

5. Detail Specifications for Building Submarines SSB(N)616 dated 1 April 1960 with Change Order No. 23.

6. Conference between LCDR G.C. Merritt (USS GEORGE WASHINGTON) and Mr. W.E. McConnaughey on 31 January 1961.

SECTION 9 - RESEARCH AND DEVELOPMENT

901. OXYGEN SUPPLY

1. ELECTROLYTIC OXYGEN GENERATOR (SPLIT CELL)

The idea for a split-cell type of oxygen generator was conceived in the mid-1950's when the Naval Research Laboratory was working with nickel-cadmium storage batteries. As a result, Naval Research Laboratory studied the feasibility of converting a battery of this type into an oxygen generator by essentially replacing the nickel-oxide electrode with a pure nickel inert electrode which would evolve a gas instead of accepting a charge. The study looked promising so a laboratory model was built and operated to prove out the concept.

Electric Boat Division was awarded a contract by the Bureau of Ships to further develop the concept and to build a 5 SCFH scaled-down prototype. This unit was completed and operated extensively--the longest continuous run being for a period of 38 days.

Electric Boat Division, with further refinement, then submitted a formal engineering proposal to manufacture full-scale shipboard split-cell generators for installation on two ships under construction by them. The proposal was accepted and, two generators each will be installed on the SSB(N)623 and SSB(N)626 as shipbuilder furnished material.

The shipboard model of the split-cell generator will consist of 66 pairs of half-cells with supporting components and controls as illustrated by Figure 9-1. Figure 9-2 represents one pair of half-cells and illustrates the principle of operation. The half-cells are connected in series so that one is charging while the other is

discharging. The cadmium electrode of the charging half-cell accepts a charge and no gas is generated, whereas the inert nickel electrode has no appreciable capacity so it evolves gas (oxygen). By the same token, the other half-cell produces hydrogen at the nickel electrode while the cadmium electrode is discharging. Of course, if a cell was allowed to reach a full charge and the current was allowed to continue in the same direction, both O_2 and H_2 would begin to be evolved in each half-cell, i.e., we would exceed the "gas free capacity" of the cadmium electrodes. Hence, before this condition can exist, as evidenced by a rise in cell voltage, the cells are evacuated and the current flow is reversed so that the half-cell previously producing oxygen now produces hydrogen. The process is continuously cycled in this manner.

The cells operate at about 3 psig. The low pressure involved yields a process which can be more easily controlled, but at the same time, does not afford the characteristic of enabling us to charge the ships oxygen banks. Conversely, the hydrogen by-product must be pressurized and pumped overboard by a hydrogen compressor (steel diaphram type). Unique characteristics of the split-cell generator compared to the mono-polar unit include: (1) a smaller quantity of instrument air is required, thus the split-cell can use ship's air and eliminate the requirement for a Nash instrument air compressor; (2) nitrogen is not required for purging, and (3) the cost of the split-cell is less than that of the mono-polar generator.

2. ELECTROLYTIC OXYGEN GENERATOR (BIPOLAR)

The bipolar oxygen generator is the second generation outgrowth of the mono-polar generator. In September 1959, M. H. Treadwell Company was awarded a contract for study of the bipolar concept and preliminary design of a full scale 120 SCFH prototype. An evaluation of the study and preliminary design showed that the bipolar generator appeared to be technically feasible and particularly advantageous. As a result, Treadwell was awarded a development contract in March 1960 for one complete shipboard unit. Testing of the assembled unit will begin in Spring 1961.

The basic difference between the bipolar generator and the present mono-polar unit is that gas is generated in only 1 cell, as can be seen in Figure 9-3). This greatly reduces the control hardware and circuitry required and will result in a more reliable and compact unit. The generating cell itself consists of 35 conical nickel electrodes stacked one on top the other, connected electrically in series. When current is applied, each electrode becomes positive on one side and negative on the other and generates oxygen and hydrogen on the positive and negative sides respectively.

In line with previous design philosophy, the bipolar generator is designed for complete unattended operation with fail-safe features and automatic shut-down in case of a malfunction. Service requirements are somewhat different from those of the mono-polar unit as can be seen by Figure 9-3. The bipolar generator will be cooled by

the ship's chilled or fresh water system and will require special 120 volt, 3 phase, 400 cycle electrical power for electronic controls. There is no instrument air requirement. Hydraulic power will be required for actuators and distilled water pump drive in an amount not to exceed .15 GPM of oil at 2500-3000 psi.

Mechanical components of the generator will be mounted internally so the generator proper will be mounted firmly to the deck.

The generator installation will include a small nitrogen generator (1 per ship) which is to be mounted externally to the O_2 generator. In this way the O_2 generator will be provided with a separate nitrogen system, independent of external contamination. The nitrogen generator is designed on the principle of regenerative oxidation of copper. Air is passed over heated copper with the result that the oxygen is extracted to form copper oxide. The nitrogen product is then passed to storage. The N_2 generator must be reactivated periodically with hydrogen, supplied as a by-product from the O_2 generator.

The bipolar oxygen generator will cost much less than the mono-polar generator and will provide 120 SCFH of oxygen in about one-half the space.

3. Sulfate Cycle

Figure 9-4 is a simplified schematic drawing of the sulfate cycle which combines oxygen supply and CO_2 removal functions in one system. (*3 & 4) Feasibility studies are underway at NRL to determine its suitability for nuclear powered submarine use. It is hoped that a shipboard design would have advantages over existing oxygen and CO_2 systems in terms of simplicity, volume, maintenance, and air contamination but more engineering data is required to determine this. The process is basically electrolysis of water but, unlike other submarine oxygen generators, the electrolyte is sodium sulfate (Na_2SO_4) which is partially converted in the electrolyzer into sulfuric acid (H_2SO_4) and sodium hydroxide (NaOH). The latter is used in a scrubber where it reacts with atmospheric CO_2 to form sodium carbonate (Na_2CO_3). Na_2CO_3 then reacts with H_2SO_4 in the stripper (or neutralizer) to reform Na_2SO_4 and release CO_2 for discharge overboard.

4. Chlorate Candle System

A change from cylindrical ($6\frac{1}{4}$" diam. X 11-3/8") to rectangular ($6\frac{1}{2}$" X $6\frac{1}{2}$" X $22\frac{1}{2}$") candles is being studied by the Bureau. Expected advantages are a decrease in the cost of oxygen and an improvement in stowage efficiency. A modification of existing furnaces would be required but they would then accommodate round as well as square candles. Work also is underway to develop

(*3 & 4) Refers to references at end of section

a throwaway filter system for furnaces -- along different lines than that tried in TRITON tests (glass wool blanket).(*5)

The major ingredient of chlorate candles is sodium chlorate ($NaClO_3$) which is a relatively inexpensive material (about \$0.10/lb, equivalent to \$0.05/scf O_2). Because of this attractive price potential, NRL is studying the direct thermal decomposition of $NaClO_3$ for possible use in nuclear powered submarines where power for heating is available.(*6)

902. CO_2 Removal

1. Freezeout

An entirely new concept in CO_2 removal is being developed into "hardware" by the Joy Manufacturing Company. This unit will remove CO_2 by freezing the CO_2 out of the air. If the development is successful, it is planned that the unit will be thoroughly tested at the U.S. Naval Engineering Experiment Station in late 1961, and that it will then be further evaluated in an operational submarine.

2. Sulfate Cycle

This process was discussed under "Oxygen Supply".

903. CO and H_2 Removal

Studies of a new design burner are described in Section 4. Anticipated advantages are longer heat exchanger life, greater installation flexibility, greater accessibility, less maintenance.

904. Analysis

1. Monoethanolamine (MEA) Detection

NRL has developed an MEA and ammonia (NH_3) detector for submarine use [*4] which has had limited evaluation at sea. There have been practical difficulties in getting satisfactory commercial production of the tubes and some difficulty in making readings at and below the submarine allowable concentration of 1 ppm MEA. [*7] However, this is the best field type procedure available and Bureau plans call for it to be made an allowance item on all nuclear powered submarines in the near future although work will continue to increase sensitivity, either by a change in design or a change in process (e.g., along the lines of a British proposal to use commercial NH_3 tubes with a boric acid prefilter).

2. Atmosphere Monitoring

The feasibility of adapting gas chromatography to the problem of nuclear powered submarine atmosphere monitoring is being studied at NRL. This technique is of interest as a possible successor to the present Atmosphere Analyzers because of its basic simplicity and versatility. Advances in chromatography are being made very rapidly in industry so the approach being made is to investigate commercial equipment for its adaptability to submarine requirements rather than to conduct independent research. To date, the results are promising and it is hoped to make shipboard studies by the end of 1961.

3. Checking

The Draeger Kit was first qualitatively evaluated at sea during the NAUTILUS "habitability cruise" of 1956.(*14) This cruise demonstrated the practicality and desirability of such equipment and it was subsequently made an allowance item. However, this was done without a technical appraisal of performance. Since then, the U.S. Public Health Service has been conducting a laboratory evaluation (*15 & 16) to determine the following for each tube type:

a. Accuracy of calibration.

b. Performance at industrial threshold limit values (TLV's), at ten times this value, and at one-tenth this value.

c. Interference by gross contaminants in submarine atmospheres (i.e., CO, CO_2, freon, methane, hydrogen).

d. Performance with continuous flow, electrical pumps instead of manufacturer's hand pump.

e. Effect of age.

The goal of this work is to obtain an assembly of tubes which is reliable and versatile so other brands of tubes will be substituted for unsatisfactory Draeger tubes and will be added to the assembly where Draeger tubes are unavailable. Specifications for such an assembly are expected by early 1962.

905. Emergency Air Breathing System

Development efforts are concerned with improving comfort and decreasing volume requirements. Current thinking is along the lines of adapting the Mark V gas mask (if visibility is satisfactory), using a miniature demand regulator mounted on the mask, and adopting smaller hose and quick connect fittings. Prototype equipment is being assembled and will be evaluated at sea in the near future. Further information on communication requirements will be sought also.

906. NRL Leak Detector

A leak detector is under development at NRL and prototype units are being provided to operating FBM submarines. Although work on this instrument was started with the intent of developing a freon leak detector for use in high ambient freon concentrations, the subsequent availability of the General Electric Model H-6 Freon Leak Detector (with proportioning tip) has changed the Bureau's interest to one of determining the suitability of and the need for a multipurpose leak detector. The NRL Leak Detector operates on the principle of thermalconductivity and, therefore, can be used to detect leaks of any gas having a thermalconductivity significantly different than ambient air. Evaluations in SKATE,(*8) TRITON,(*5) and SKIPJACK (*9) have demonstrated its utility for CO_2 and oxygen leaks as well as for freon. It is especially suited to hydrogen leaks which may be of value for oxygen generator installations.

907. Fleet Assist Project

CNO has established a continuing project to "Assist the Bureau of Ships in Continuing a Nuclear Powered Submarine Atmospheric Habitability Test Program" (*10) in connection with Operational Requirement Number PO-12101 (Revised) (Improve Physiological Environment Aboard Submarines). (*11)

Three types of tests are carried out under this project. Type a) is carried out by ship's force using test equipment and instructions provided by the Bureau. The most important examples of this are the newly initiated hydrocarbon and aerosol monitoring programs (*12) to determine the requirements and effectiveness of installed control facilities.

Type b) are limited scope tests involving passage of one or two civilian technical personnel in a nuclear powered submarine for a period of 3-10 days to carry out specific tests and evaluations. An example of this type was a cruise involving two NRL personnel in USS HALIBUT (SS(N)587) to study the effectiveness and life of carbon filters. (*13)

Type c) are broad scope tests involving passage of 2-4 civilian technical personnel in a nuclear powered submarine for a period of 2-4 weeks to make general, exploratory studies during long submergences. An example of this type was a cruise in USS TRITON (SS(N)586) in which an integrated team of personnel from U.S. Public Health Service, NRL, and the Bureau studied all aspects of atmosphere control during a 26 day dive followed by two weeks of short dives

and intermittent snorkel operation.(*5)

This project is expected to continue for several more years and is of great value to the Bureau in providing scientific information to guide development of submarine atmosphere control equipment.

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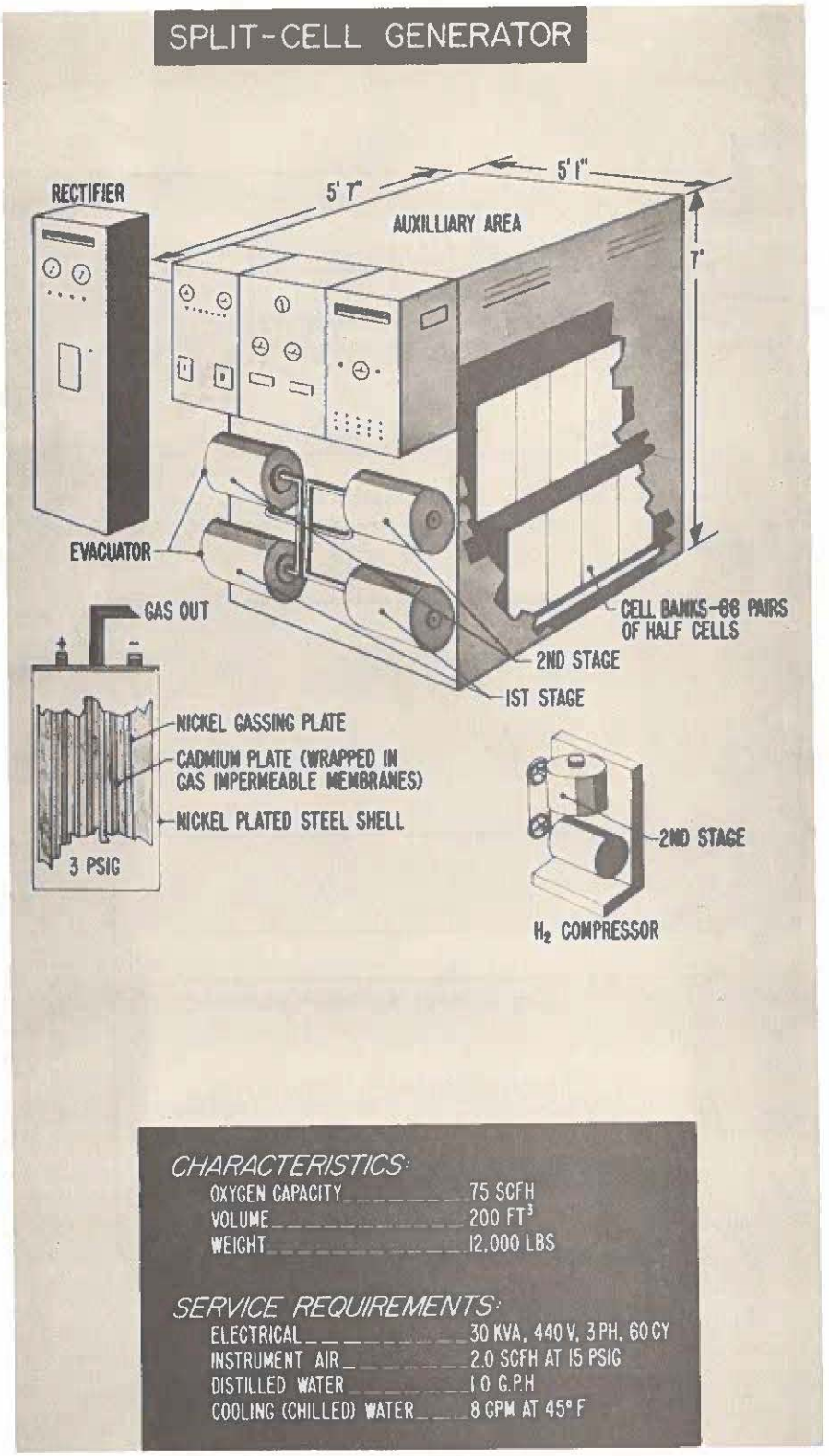
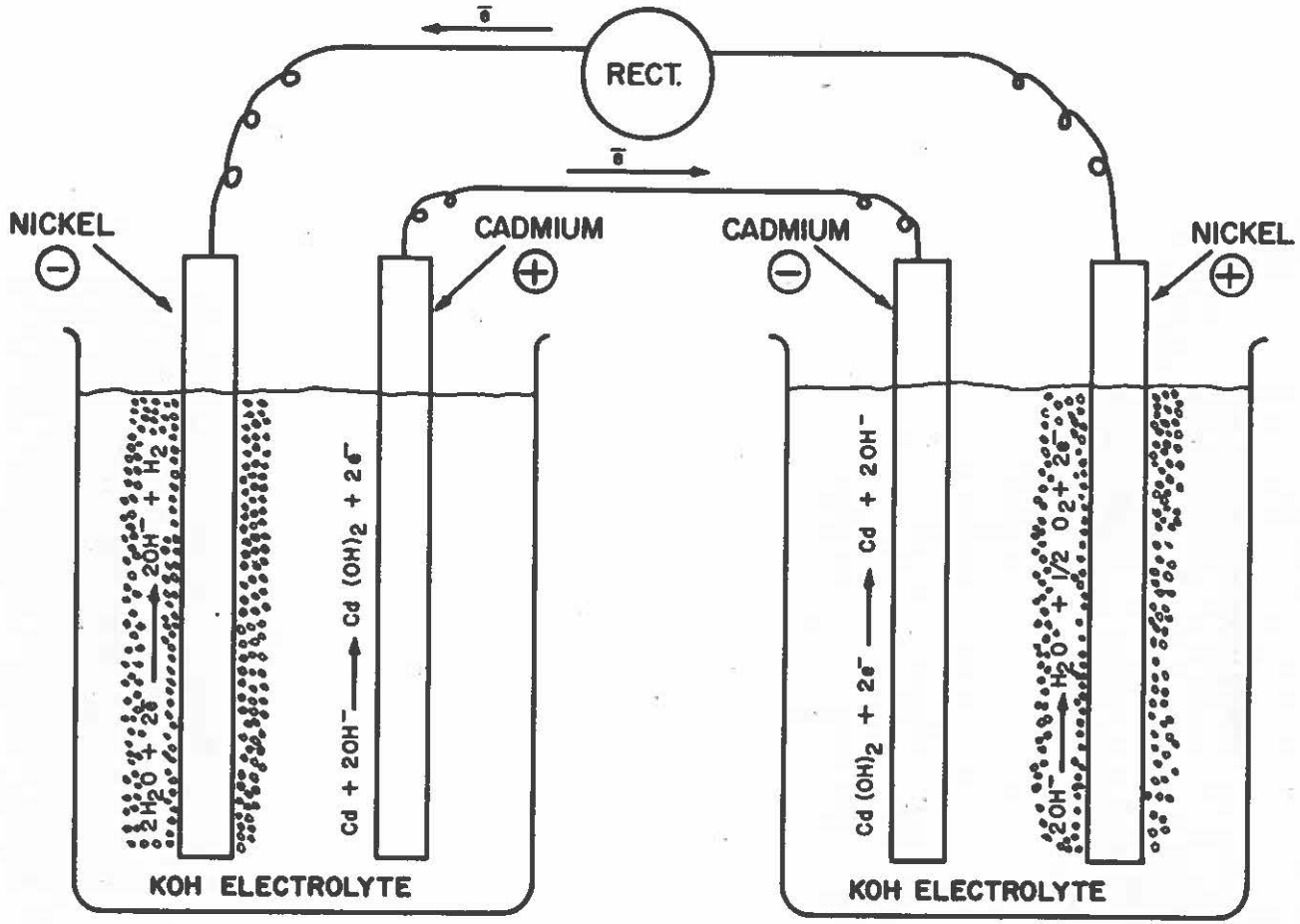

SPLIT-CELL GENERATOR
RECTIFIER
5' 7"
5' 1"
AUXILLIARY AREA
7'
EVACUATOR
GAS OUT
CELL BANKS-66 PAIRS OF HALF CELLS
2ND STAGE
IST STAGE
NICKEL GASSING PLATE
CADMIUM PLATE (WRAPPED IN GAS IMPERMEABLE MEMBRANES)
NICKEL PLATED STEEL SHELL
3 PSIG
2ND STAGE
H_2 COMPRESSOR
CHARACTERISTICS:
OXYGEN CAPACITY 75 SCFH
VOLUME 200 FT³
WEIGHT 12,000 LBS
SERVICE REQUIREMENTS:
ELECTRICAL 30 KVA, 440 V, 3 PH, 60 CY
INSTRUMENT AIR 2.0 SCFH AT 15 PSIG
DISTILLED WATER 1.0 G.P.H
COOLING (CHILLED) WATER 8 GPM AT 45° F

FIGURE 9-1



DISCHARGING CELL - H_2

$Cd + 2H_2O \longrightarrow Cd(OH)_2 + H_2$

CHARGING CELL - O_2

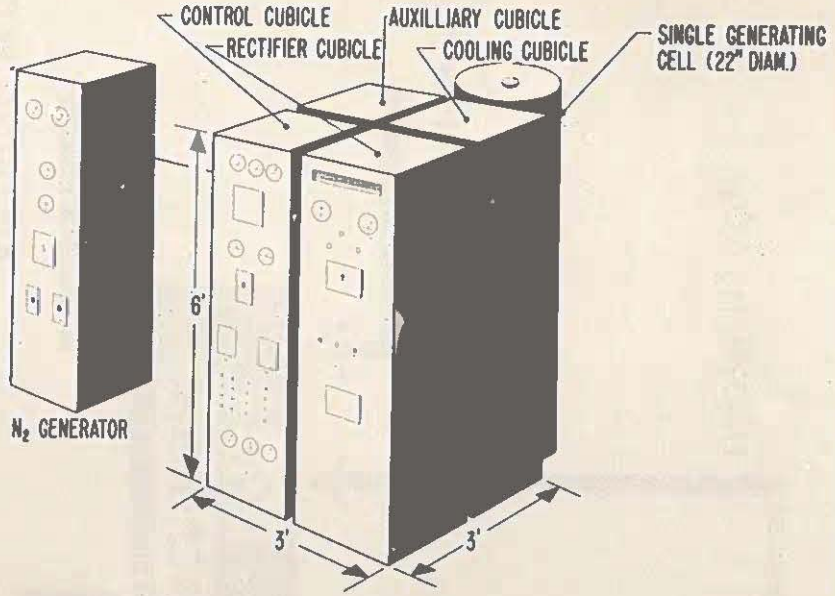
$Cd(OH)_2 \longrightarrow Cd + H_2O + 1/2\ O_2$

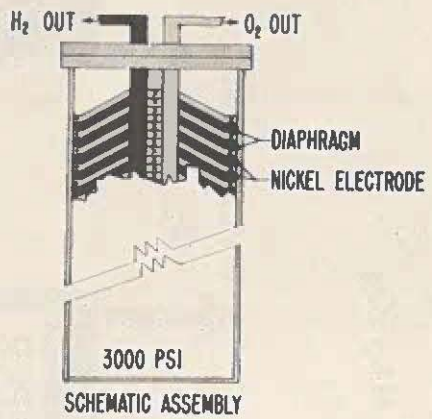
TOTAL CELL REACTION $H_2O \longrightarrow H_2 + 1/2\ O_2$

NICKEL-CADMIUM SPLIT-CELL ELECTROLYTIC OXYGEN GENERATOR

FIGURE 9-2

BIPOLAR GENERATOR





SCHEMATIC ASSEMBLY

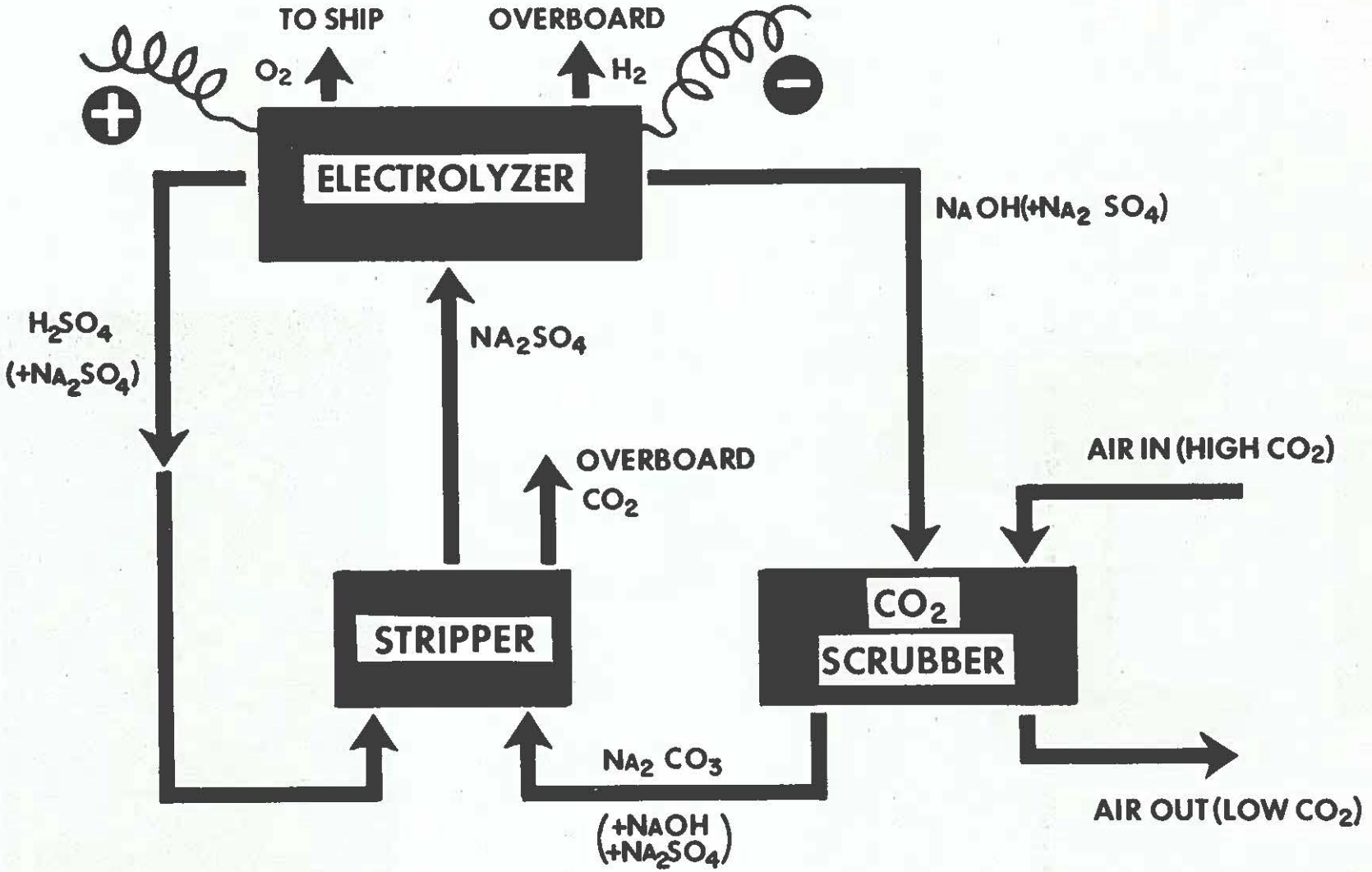
CHARACTERISTICS:

OXYGEN CAPACITY	120 SCFH, 3000 PSI
VOLUME	75 FT^3
WEIGHT	10,000 LBS

SERVICE REQUIREMENTS:

ELECTRICAL	65 KW, 440 V, 3 PH, 60 CY.
SPECIAL ELECTRICAL FOR ELECTRONIC CONTROLS	200 WATTS, 120 V, 3 PH, 400 CY
INSTRUMENT AIR	NONE
NITROGEN	150 SCF/CYCLE
DISTILLED WATER	1.5 GPH
HYDRAULIC POWER	15 G.P.M. OF OIL@ 2500-3000 PSIG
COOLING WATER	CHILLED OR FRESH WATER; MAX. REQ. 15 GPM OF 50°F CHILLED WATER

FIGURE 9-3



SCHEMATIC OF SODIUM SULFATE CYCLE

FIGURE 9-4